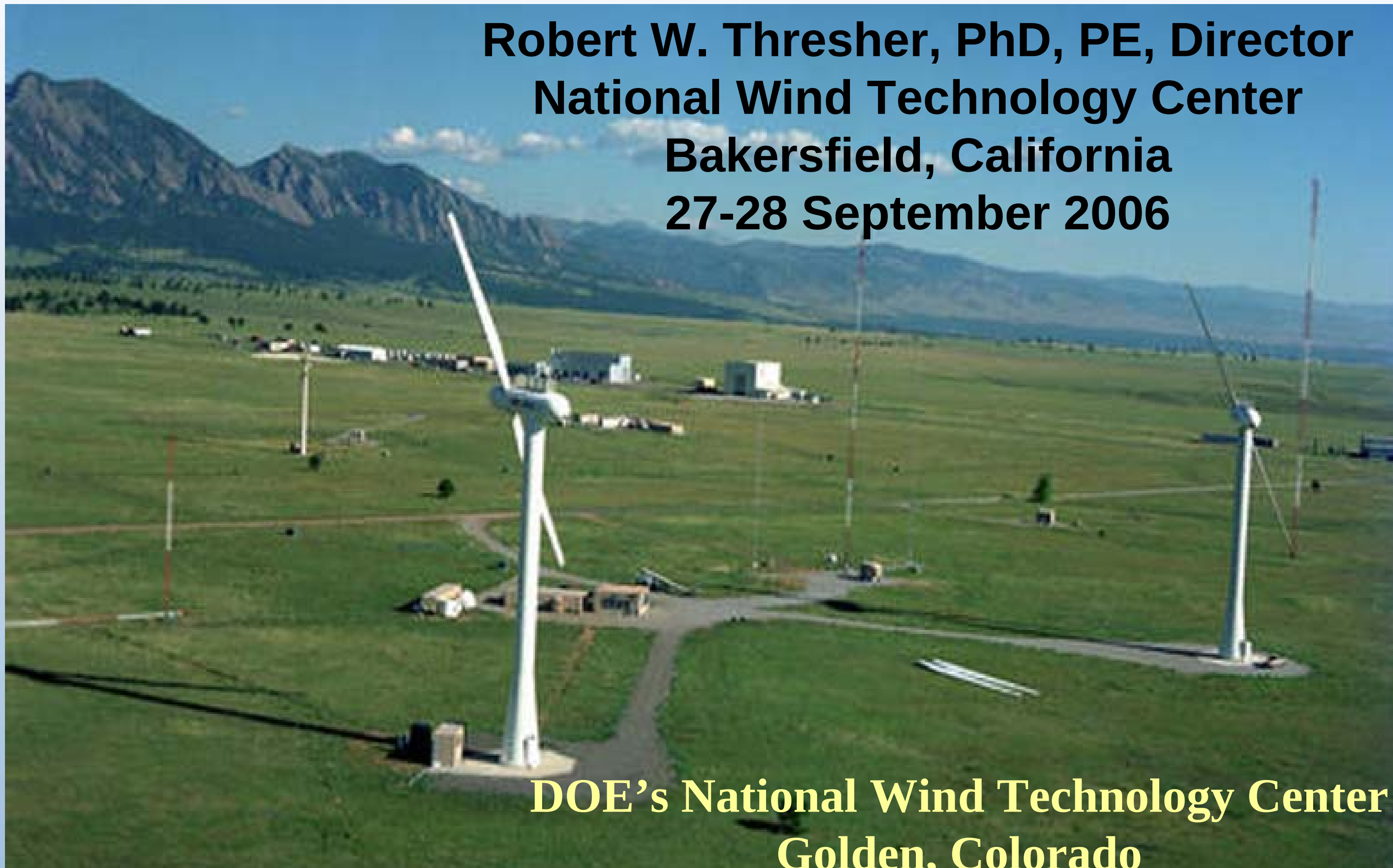
Wind Technology and Wildlife Interactions

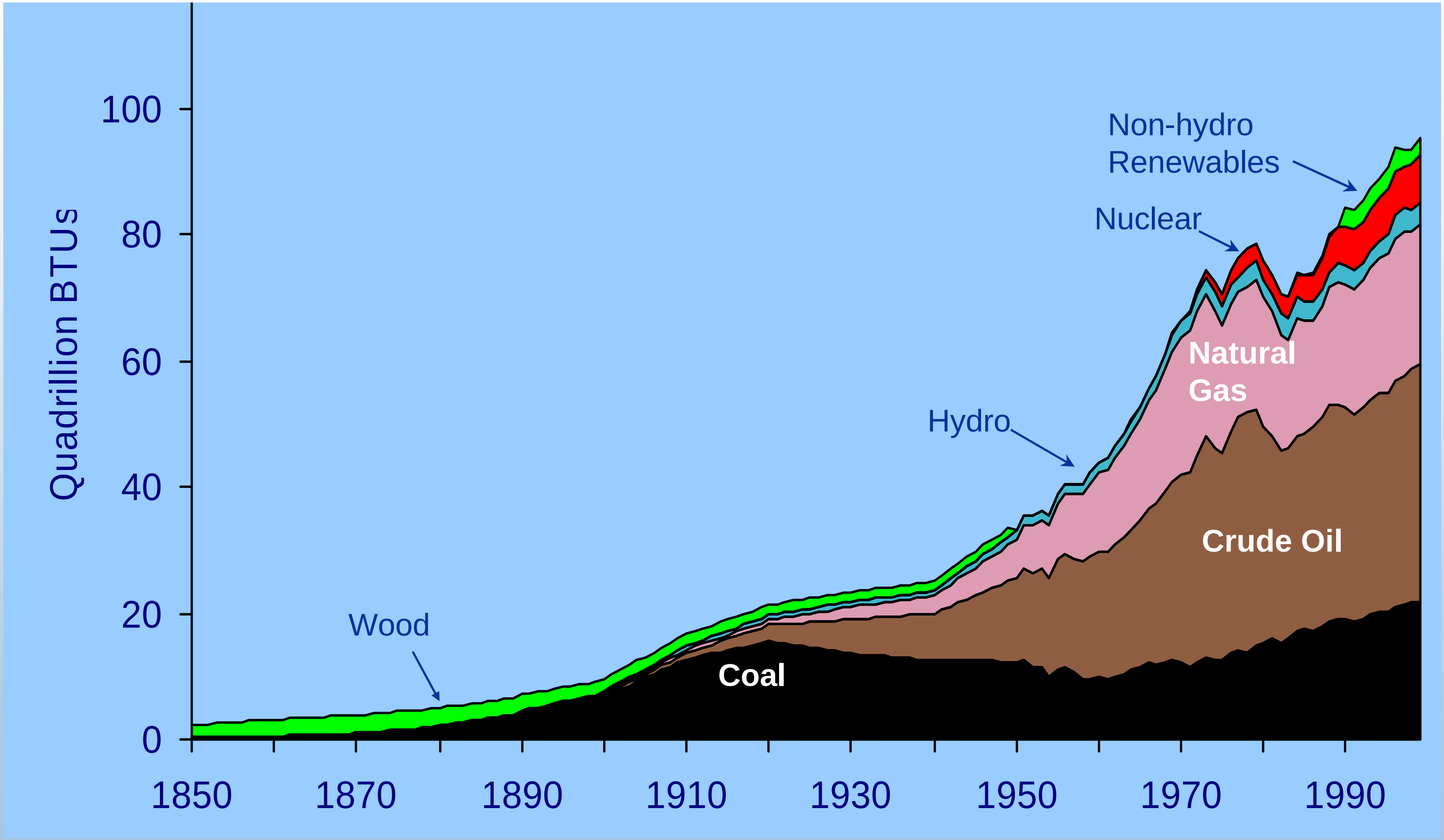
Robert W. Thresher, PhD, PE, Director
National Wind Technology Center
Bakersfield, California
27-28 September 2006



DOE's National Wind Technology Center
Golden, Colorado

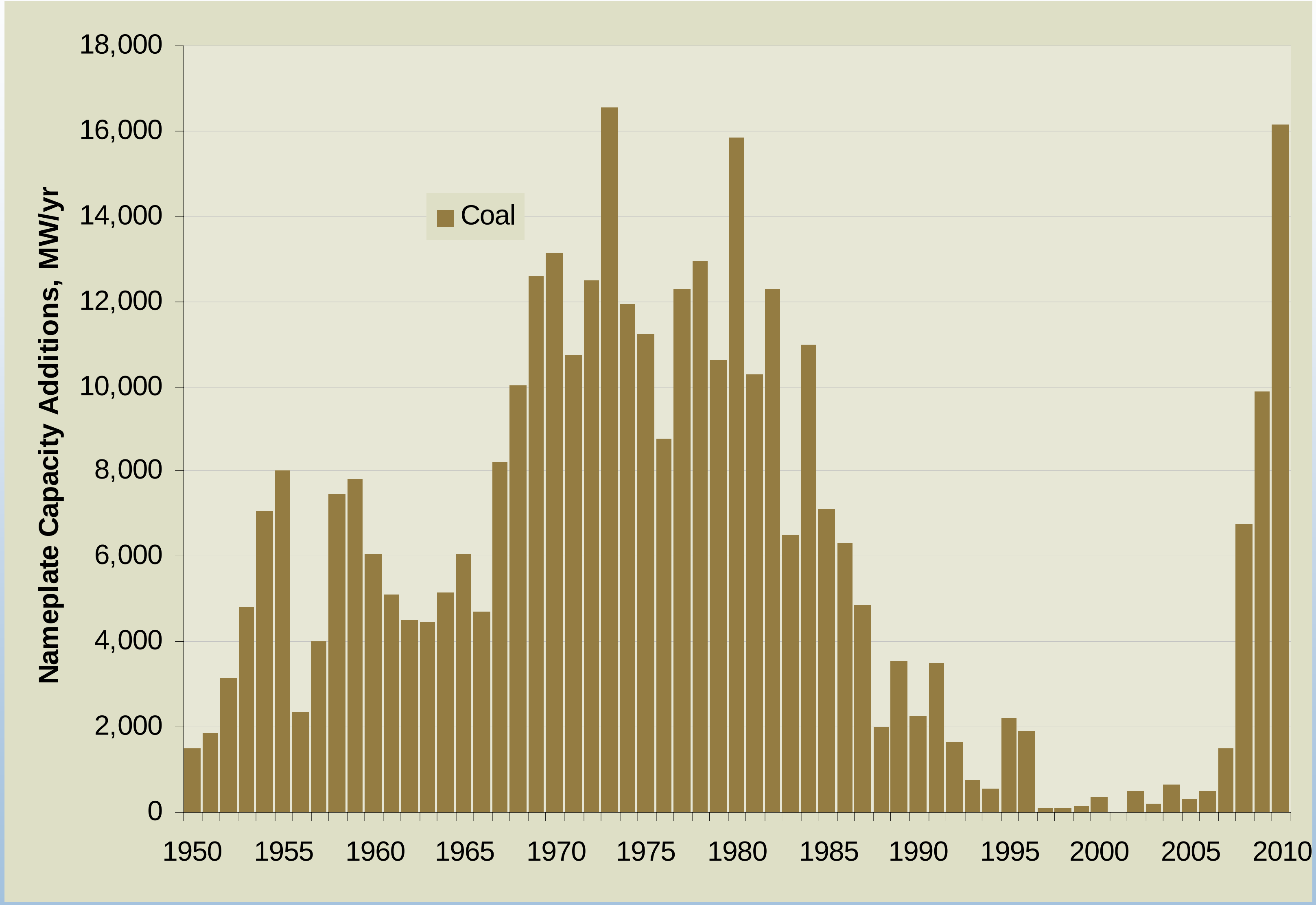
The U.S. Energy Picture

by source - 1850-1999



Source: 1850-1949, Energy Perspectives: A Presentation of Major Energy and Energy-Related Data, U.S. Department of the Interior, 1975; 1950-1996, Annual Energy Review 1996, Table 1.3. Note: Between 1950 and 1990, there was no reporting of non-utility use of renewables. 1997-1999, Annual Energy Review 1999, Table F1b.

The US History and Future Planned Additions of Coal Generated Electricity



Source: Black & Veatch Analysis of data from Global Energy Decisions Energy Velocity database

A New Vision

For Wind Energy in the U.S.

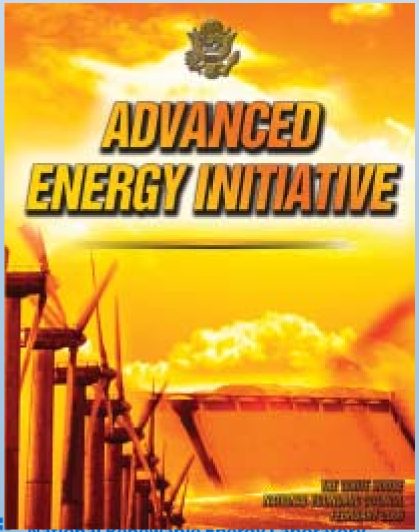
White House photo by Eric Draper

State of the Union Address

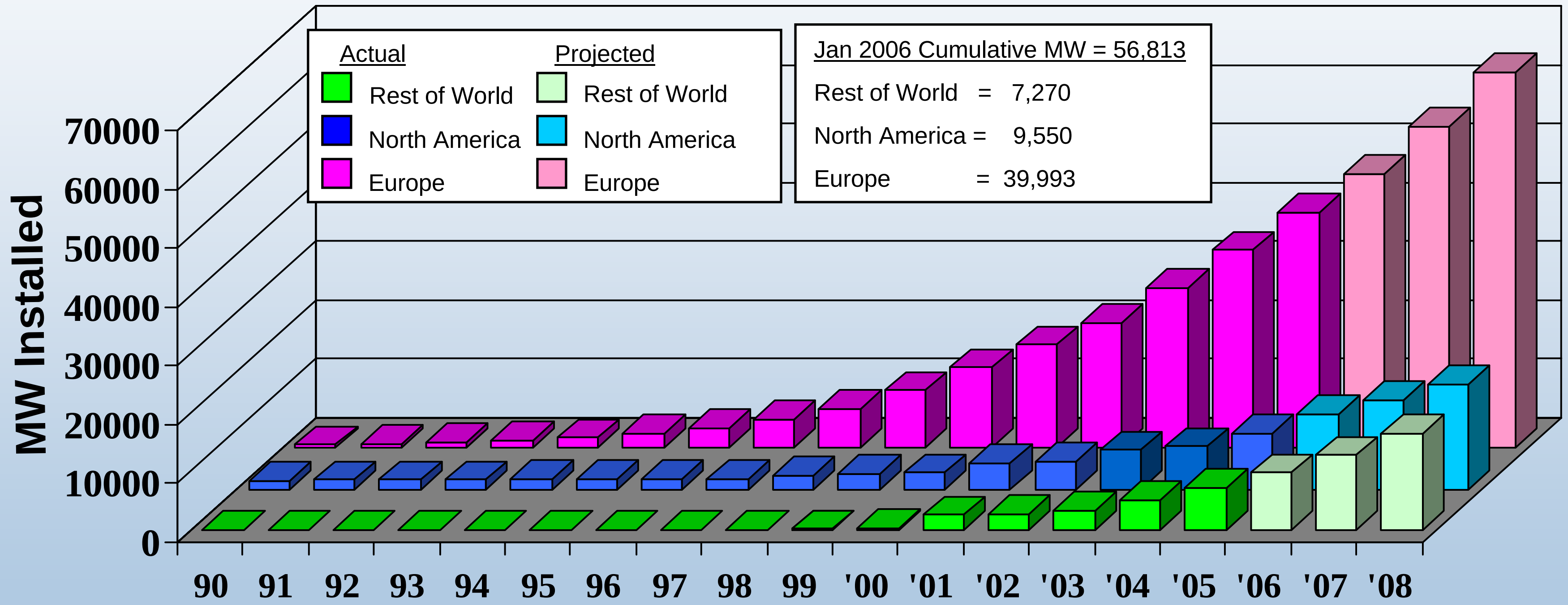
"…We will invest more in … **revolutionary** and solar **wind technologies**"

Advanced Energy Initiative

"Areas with good wind resources have the potential to **supply up to 20% of the electricity** consumption of the United States."

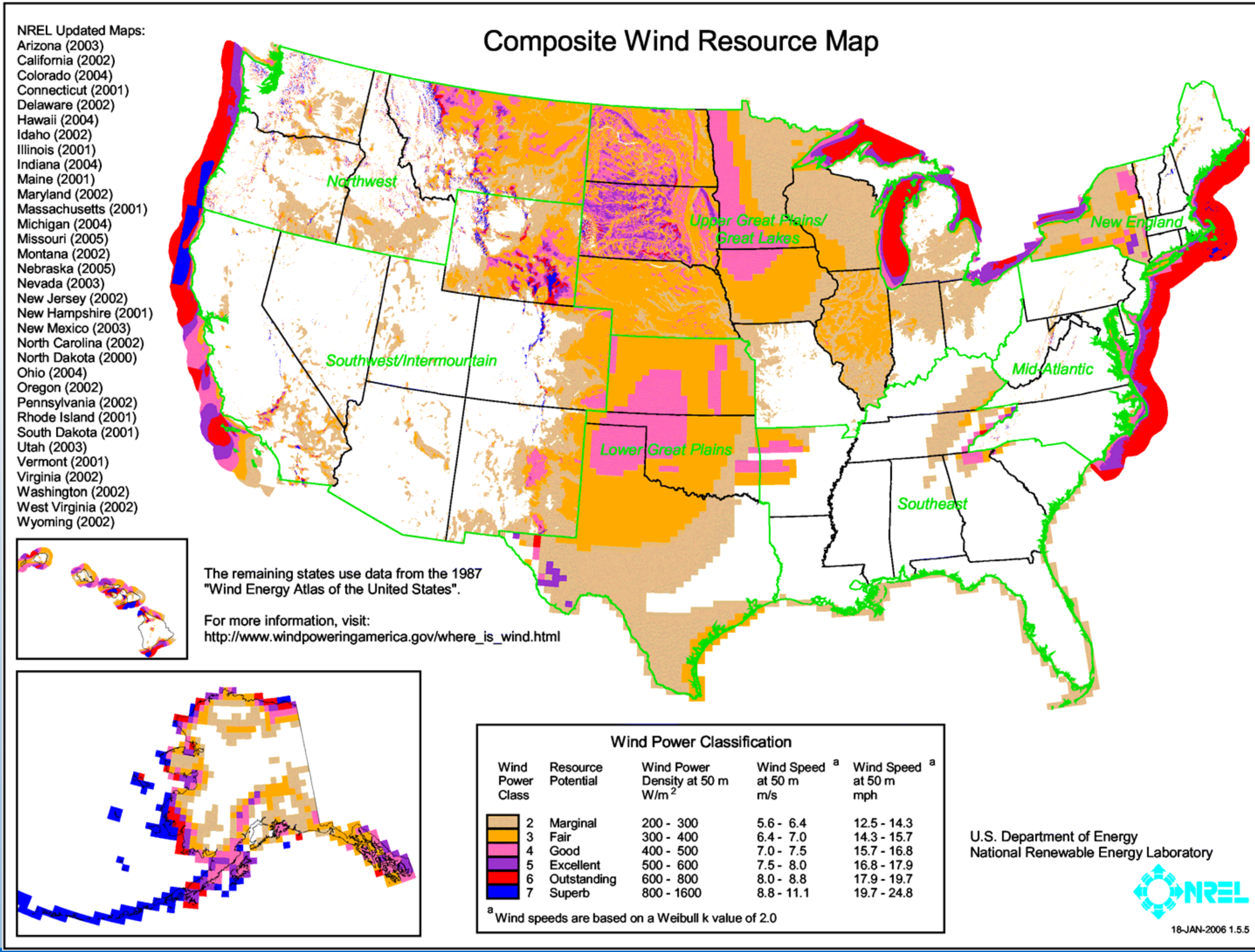


Growth of Wind Energy Capacity Worldwide

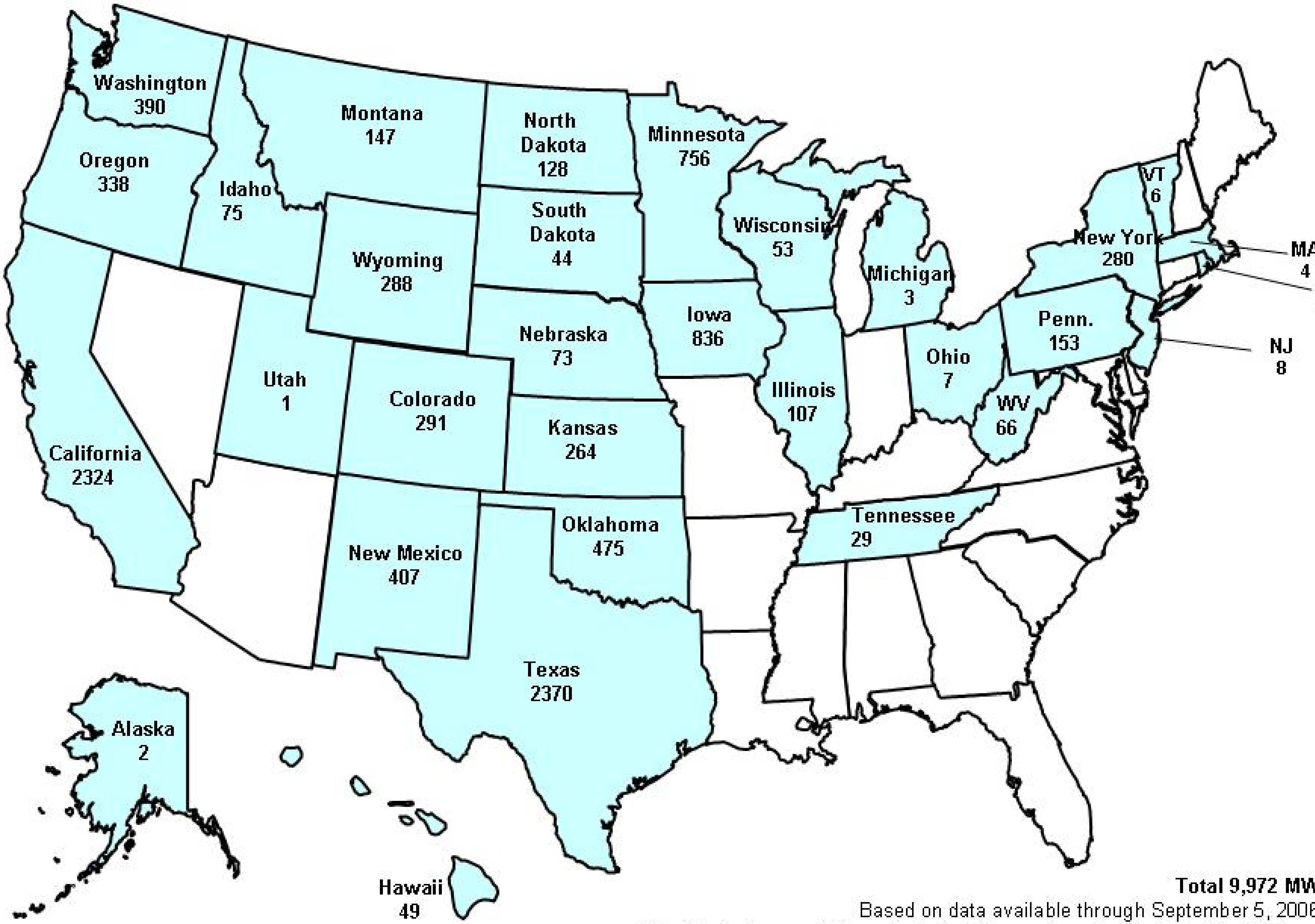


Sources: BTM Consult Aps, Sept 2005
Windpower Monthly, January 2006

National Renewable Energy Laboratory


Composite Wind Resource Map
NREL Updated Maps:
Arizona (2003)
California (2002)
Colorado (2004)
Connecticut (2001)
Delaware (2002)
Hawaii (2004)
Idaho (2002)
Illinois (2001)
Indiana (2004)
Maine (2001)
Maryland (2002)
Massachusetts (2001)
Michigan (2004)
Missouri (2005)
Montana (2002)
Nebraska (2005)
Nevada (2003)
New Jersey (2002)
New Hampshire (2001)
New Mexico (2003)
North Carolina (2002)
North Dakota (2000)
Ohio (2004)
Oregon (2002)
Pennsylvania (2002)
Rhode Island (2001)
South Dakota (2001)
Utah (2003)
Vermont (2001)
Virginia (2002)
Washington (2002)
West Virginia (2002)
Wyoming (2002)
Northwest
Upper Great Plains/
Great Lakes
New England
Southwest/Intermountain
Mid-Atlantic
Lower Great Plains
Southeast
The remaining states use data from the 1987
"Wind Energy Atlas of the United States".
For more information, visit:
http://www.windpoweringamerica.gov/where_is_wind.html
Wind Power Classification
Wind Power Class
Resource Potential
Wind Power Density at 50 m W/m²
Wind Speed [a] at 50 m m/s
Wind Speed [a] at 50 m mph
2 Marginal 200 - 300 5.6 - 6.4 12.5 - 14.3
3 Fair 300 - 400 6.4 - 7.0 14.3 - 15.7
4 Good 400 - 500 7.0 - 7.5 15.7 - 16.8
5 Excellent 500 - 600 7.5 - 8.0 16.8 - 17.9
6 Outstanding 600 - 800 8.0 - 8.8 17.9 - 19.7
7 Superb 800 - 1600 8.8 - 11.1 19.7 - 24.8
[a] Wind speeds are based on a Weibull k value of 2.0
U.S. Department of Energy
National Renewable Energy Laboratory
NREL
18-JAN-2006 1.5.5

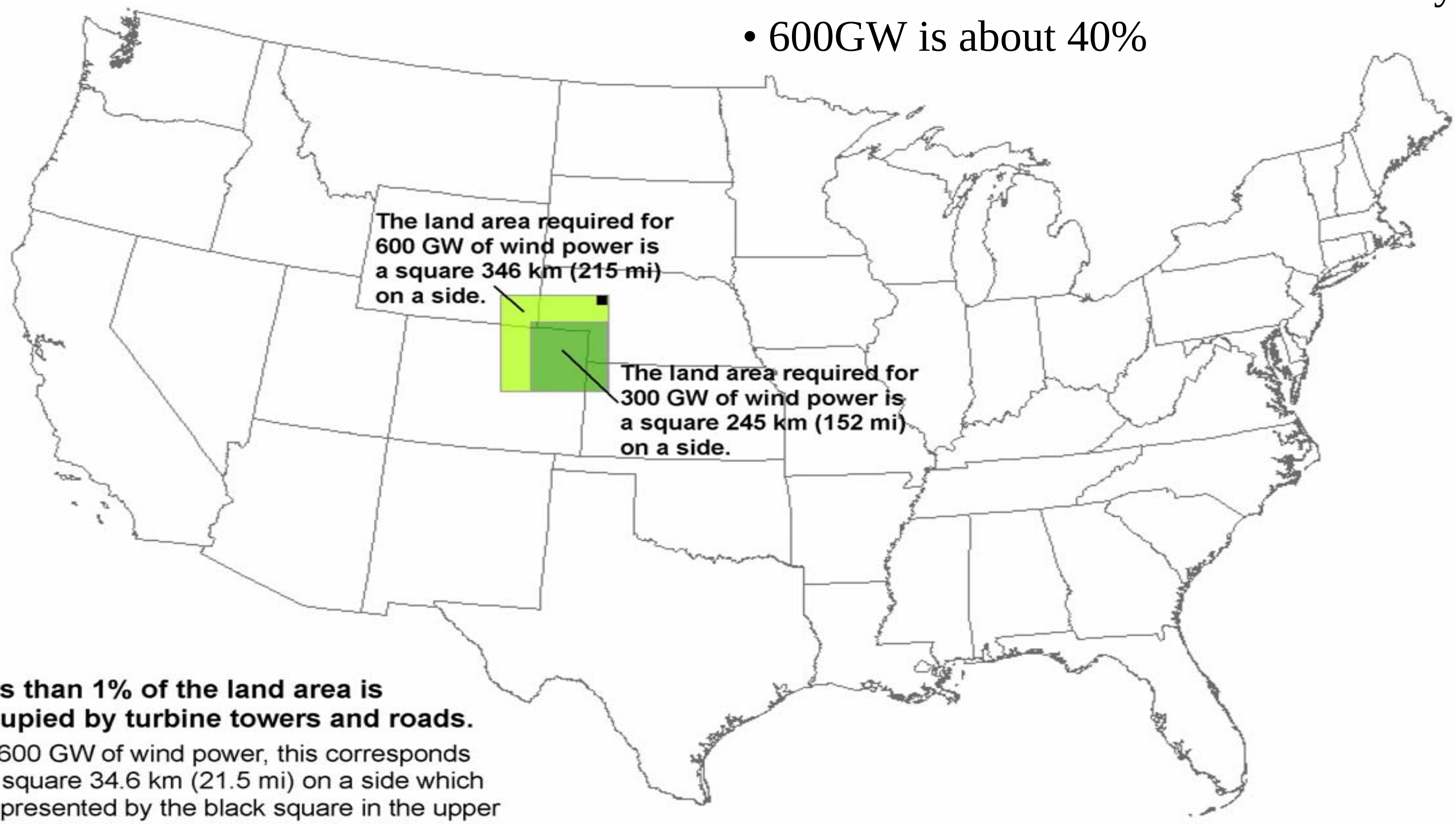
Megawatts of Installed Utility-Scale Wind Power at June 30, 2006



Total 9,972 MW
Based on data available through September 5, 2006
Blank indicates no utility-scale installations or less than 1 MW of installations

Land Requirements for 20% of the Nations Electricity

- 300GW is about 20% of US Electricity
- 600GW is about 40%



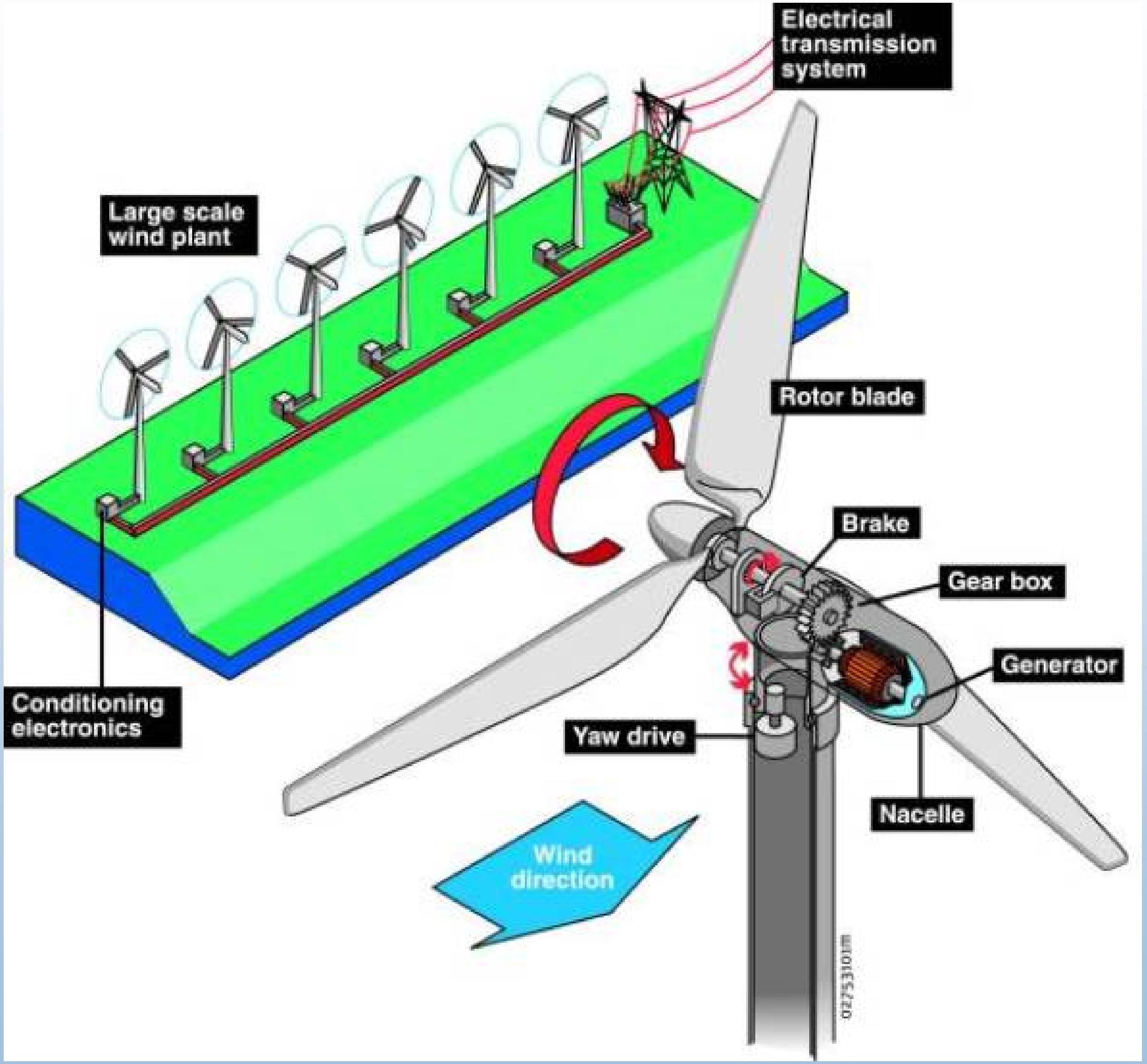
Less than 1% of the land area is occupied by turbine towers and roads.

For 600 GW of wind power, this corresponds to a square 34.6 km (21.5 mi) on a side which is represented by the black square in the upper right corner. The majority of land area in a wind farm remains available for its original use such as ranching or farming.

U.S. Department of Energy
National Renewable Energy Laboratory
NREL
16-MAY-2006

Schematic of Wind Plant

At it's simplest, the wind turns the turbine's blades, which spin a shaft connected to a generator that makes electricity.



Large turbines are grouped together in an array of about 5 Diameters by 10 Diameters to form a wind power farm, which feeds electricity to the grid.

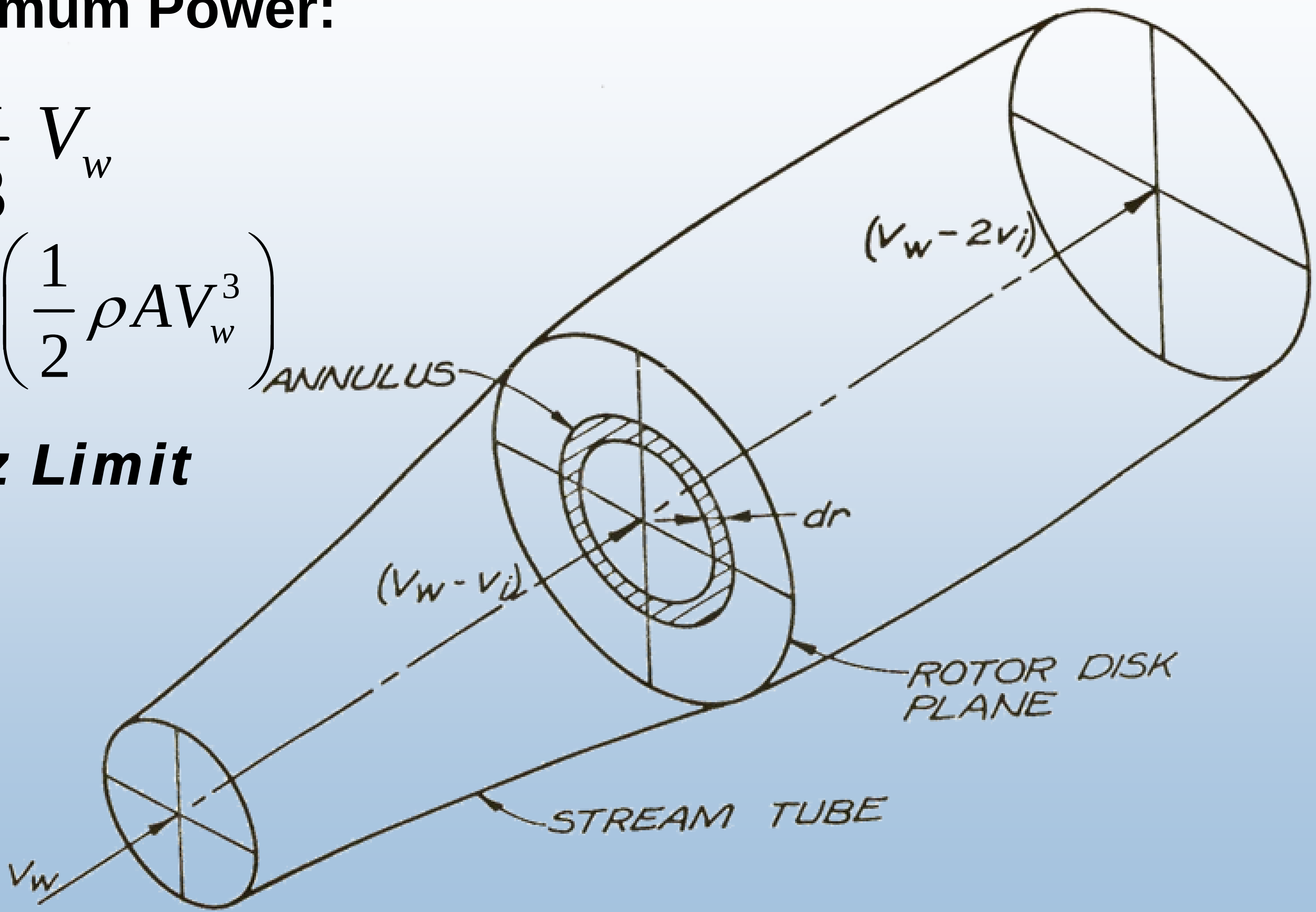
Stream Tube for Momentum Balance

For Maximum Power:

$$V_i = \frac{1}{3} V_w$$

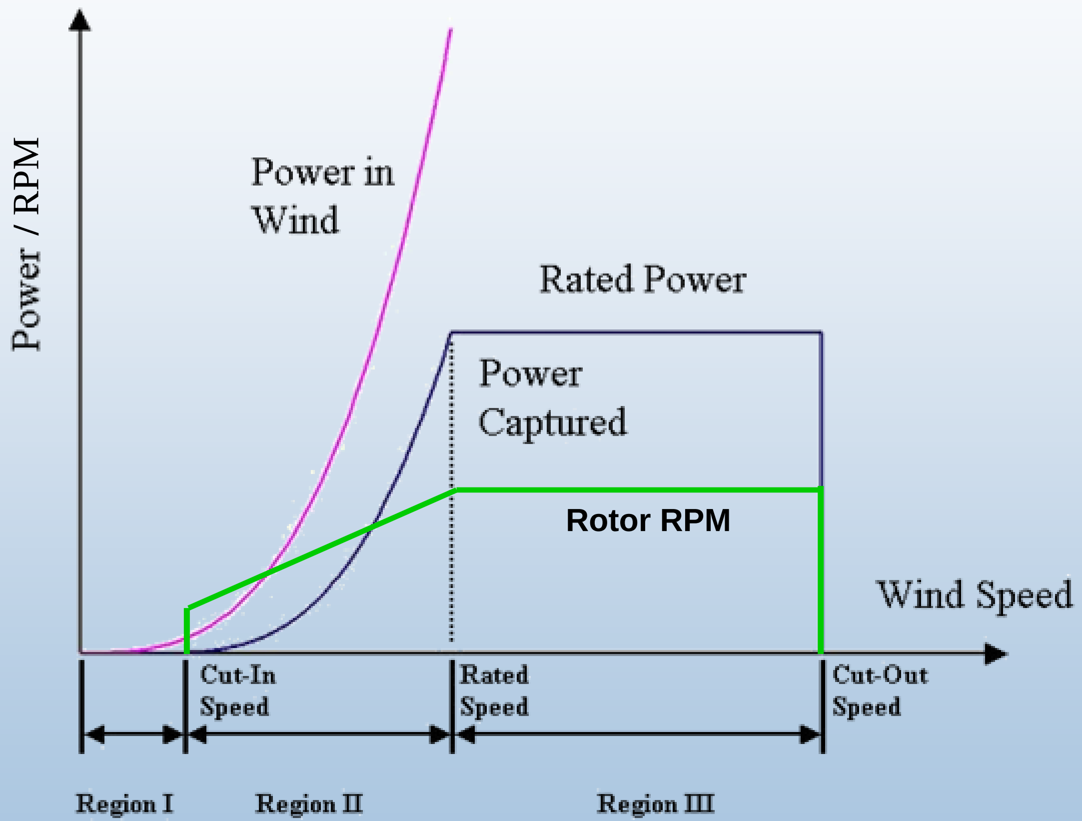
$$P = \frac{16}{27}\left(\frac{1}{2}\rho A V_w^3\right)$$

The Betz Limit



Wind Energy Production Terms

- *Power in the Wind* = $1/2\rho AV^3$
- *Power Coefficient* - C_p
- *Betz Limit* - 59% Max
- Efficiency – about 80%
- *Rated Power* – Maximum power generator can produce
- *Capacity factor* - Annual energy capture / Generator max output X 8760
- *Cut-in* wind speed where energy `production begins
- *Cut-out* wind speed where energy production ends



Modern Turbine Power Curve

Consideration for Siting a Wind Farm

- Income = Energy Output ~ $(\text{Wind Speed})^3$
- Transmission Access
- Power Purchase Agreement with Utility
- Land with landowner willing to lease
- Permits: Minimal Wildlife & NIMBY
- Turbines at a Competitive Price
- Financing

A Utility Scale 1.5 MW Wind Turbine

Cost of Energy Trend

1981: 40 cents/kWh

NSP 107 MW Lake Benton, MN wind farm

Decreasing Cost Due to:

- Increased Turbine Size
- R&D Advances
- Manufacturing improvements

2006: 5-8 cents/kWh with no PTC for a 13mph wind speed at 10m (18mph at 100m hub)

Recent cost increases are due to:

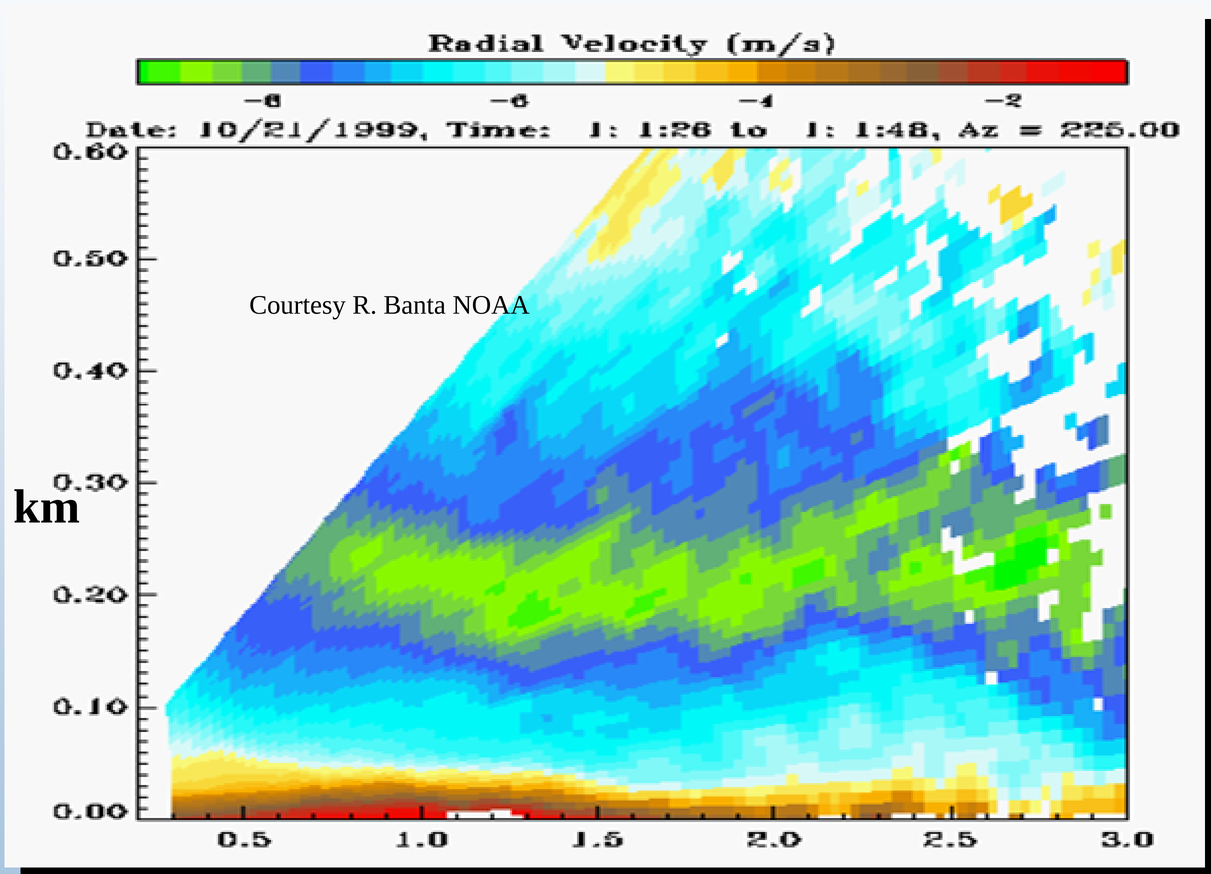
- Price increases in steel & copper
- Turbines sold out for 2 years

Note: These energy costs are average for the US and costs in many locations with lower winds at hub height, higher insurance, permitting, and land cost, such as in California can increase energy cost by up to 20%.

2012 Goal :

3.6 cents/kWh with no PTC for a site with a hub height wind speed of ~ 18mph

Measuring and Modeling the Low-Level Nocturnal Jet



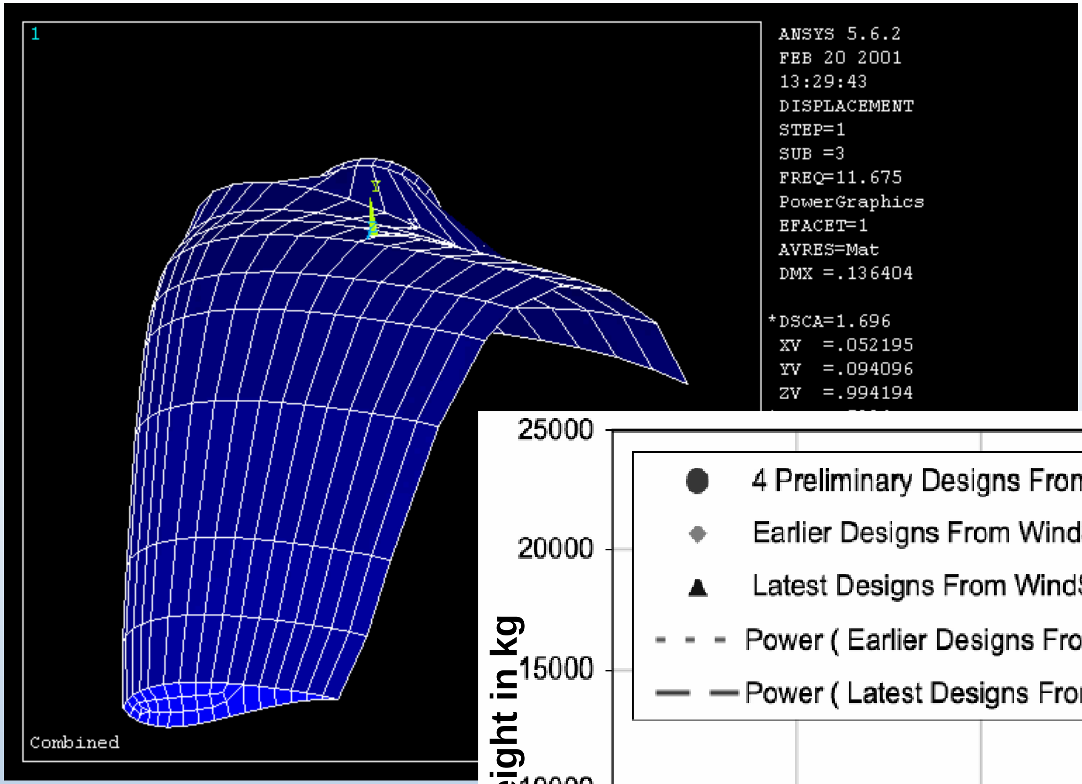
km

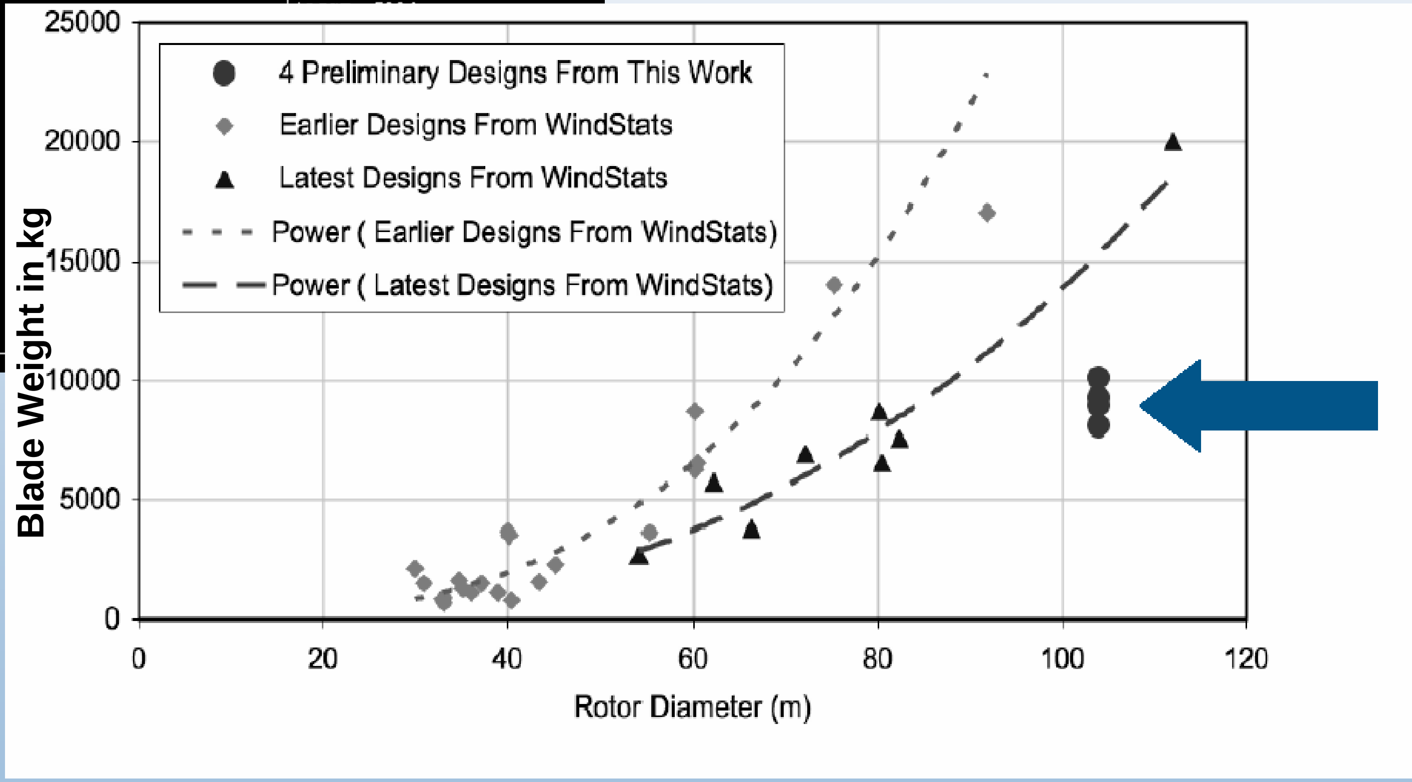
Met tower and SODAR at Lamar, Colorado

Blade Fatigue Testing at NREL

A new 45-meter wind turbine blade was shipped to the NWTC for testing in July 2004.

Blade Scaling for Multi-megawatt Rotors





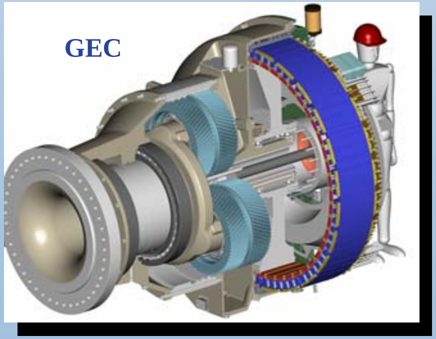
NREL Advanced Drivetrain R&D

Tomorrow

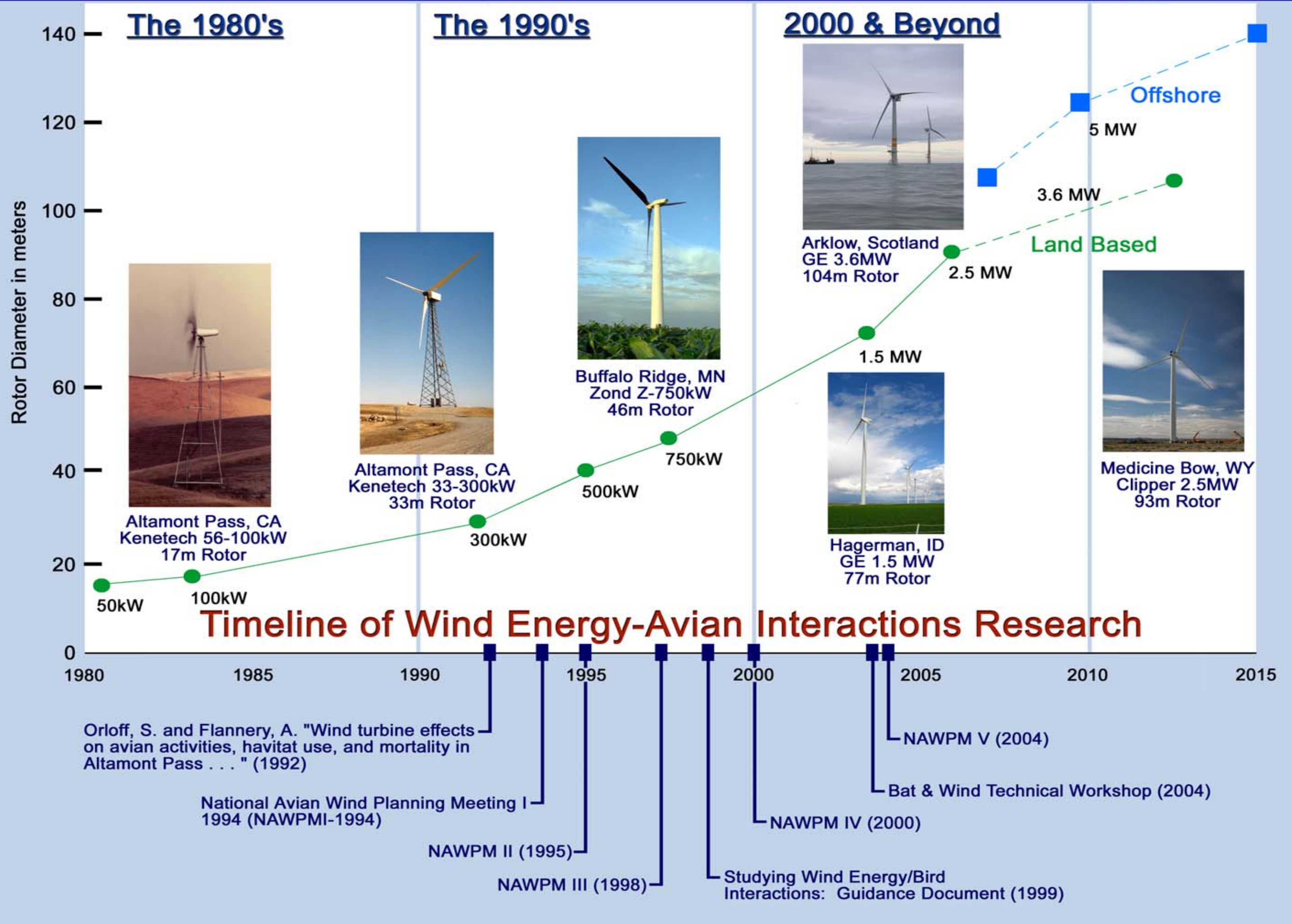
Prototype Technology

Today

1.5MW Commercial Technology



Evolution of U.S. Commercial Wind Technology



National Avian – Wind Power Planning Meeting I
July 1994

Meeting Outcome: Five Major Research Areas

- Assess mortality attributable to wind turbines at existing sites (including control data from “no turbine” sites)
- Predict mortality at planned wind power sites, based in part on previous bullet
- Predict population consequences
- Identify ways to reduce bird kills at wind plants
- Set values for off-site mitigation

Key Research Studies Proposed to the NWCC Avian Subcommittee - NAWPP II (June 1995)

I. Avian Wind Farm Interaction Studies

- **Observe and measure the effects of wind farms on avian species in the area**
- **Use a BACI approach where possible**

	Before	*After*
Wind Farm site	*X*	*X*
Reference site	*X*	*X*

II. Avian Risk Reduction Studies

Consider: *- Visual enhancement*
- Tower type
- Perch guard
- Acoustic
- Decoys

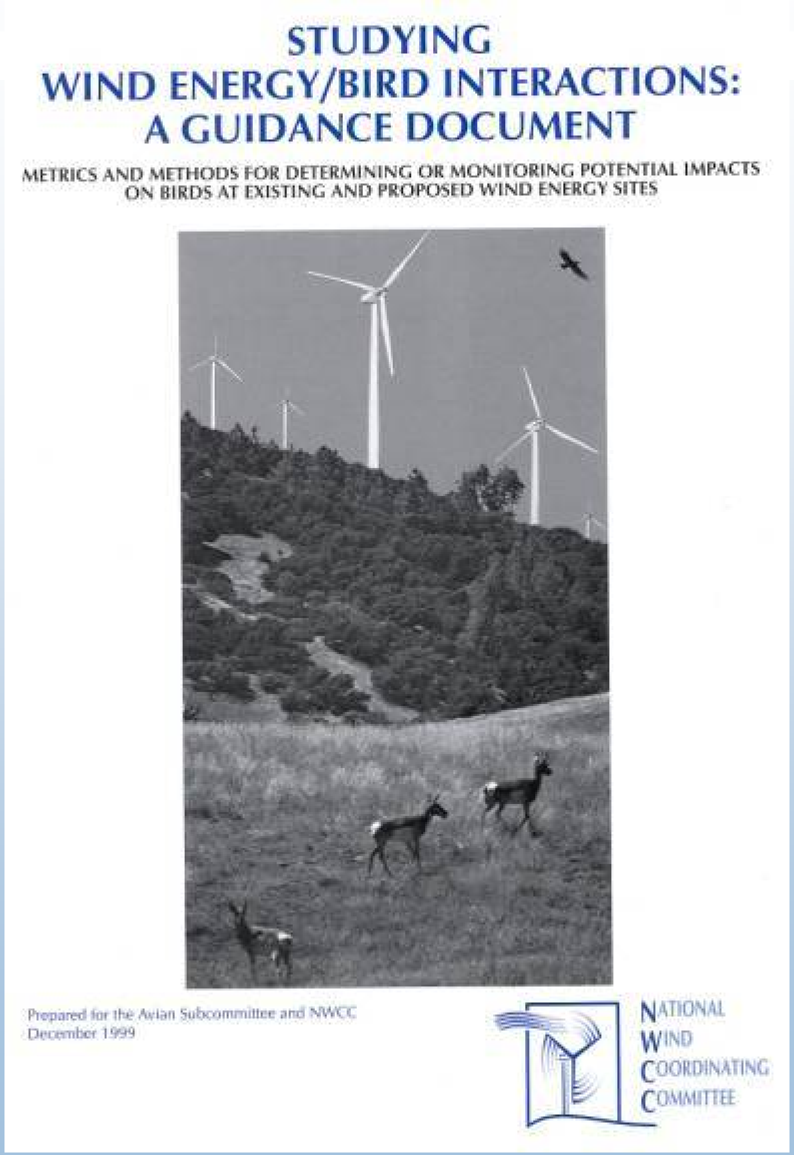
Compare treated and untreated turbine while measuring utilization, mortality and observing behavior

Key Research Studies Proposed to the NWCC Avian Subcommittee - NAWPP II (June 1995)

Associated research recommendations:

- Develop standardized measurement protocols and guidelines
  - For comparability from different studies
  - To guide researchers
  - To be able to understand differing results
- Study population impacts using
  - Model studies to better understand the effects
  - Actual field measurements on a target avian population

NWCC Avian Guidance Document



Assessing the suitability of a proposed wind farm site with regard to avian concerns is an important component of overall site evaluation. This NWCC document provides guidelines for conducting avian assessments.

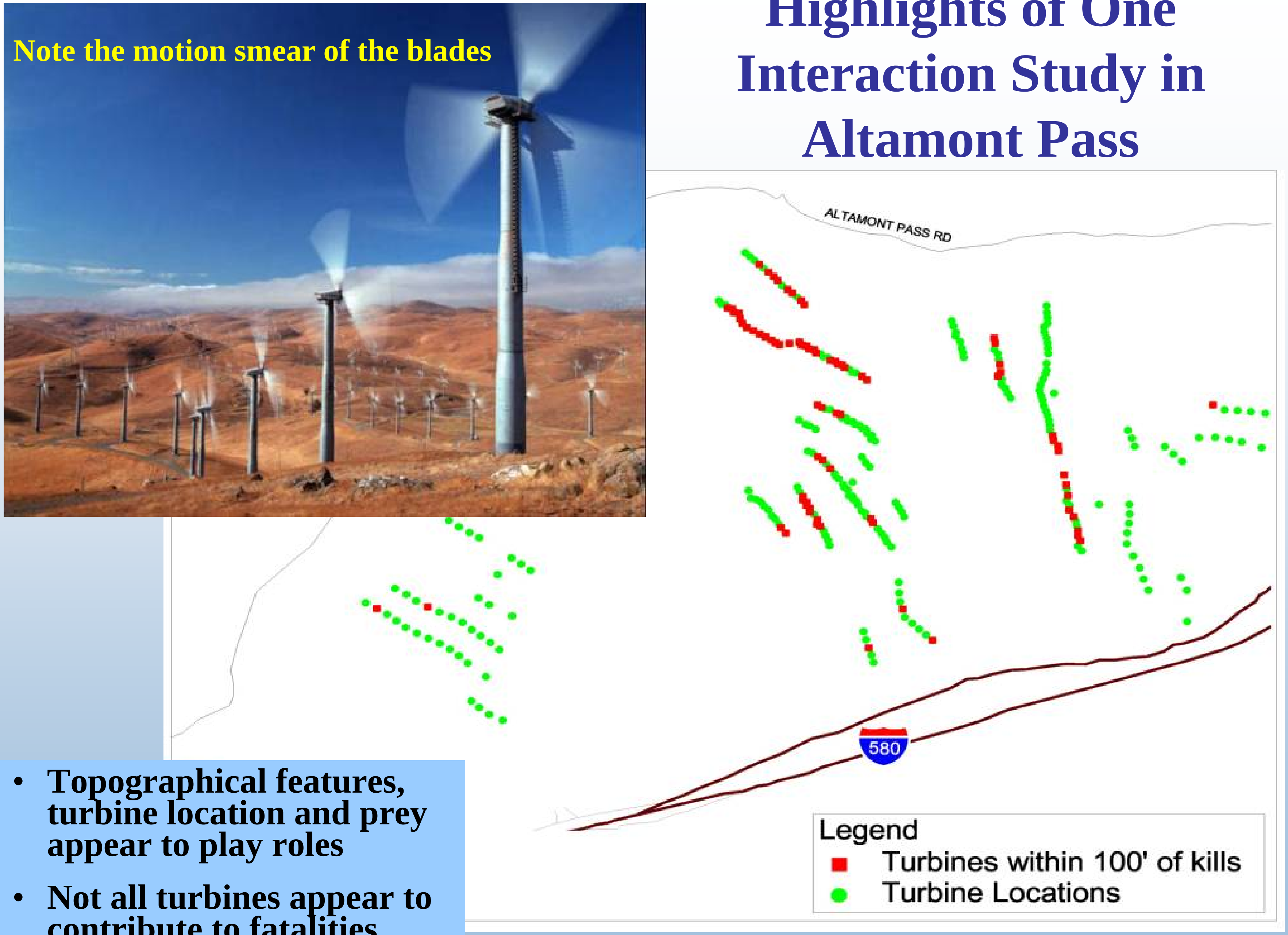
Published December 1999.

NREL Avian Studies Available at:

http://www.nrel.gov/wind/avian_lit.html

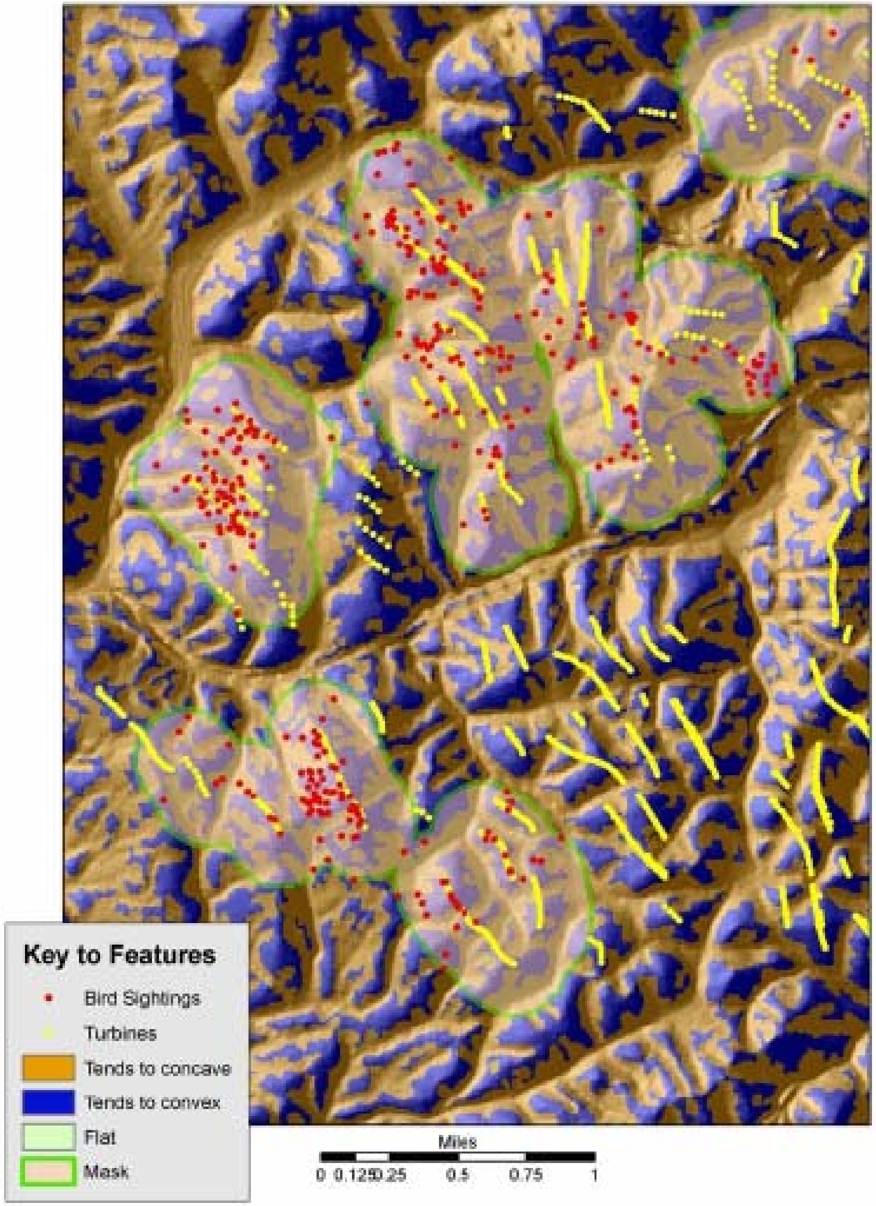
- Permitting of Wind Energy Facilities: A Handbook
- A Pilot Golden Eagle Population Study in the Altamont Pass Wind Resource Area, California
- A Population Study of Golden Eagles in the Altamont Pass Wind Resource Area, Second-Year Progress Report
- Ponnequin Wind Energy Project – Reference Site Avian Study
- A Population Study of Golden Eagles in the Altamont Pass Wind Resource Area: Population Trend Analysis 1994-1997
- Predicting the Response of Bird Populations to Wind Energy-Related Deaths
- The Response of Red-Tailed Hawks and Golden Eagles to Topographical Features, Weather, and Abundance of a Dominant Prey Species at the Altamont Pass Wind Resource Area, California, April 1999-December 2000
- Searcher Bias and Scavenging Rates in Bird/Wind Energy Studies
- Status of Avian Research at the National Renewable Energy Laboratory (2001)
- Status of the US Dept. of Energy/NREL Avian Research Program (1999)
- Studying Wind Energy/Bird Interactions: A Guidance Document

Highlights of One Interaction Study in Altamont Pass



- **Topographical features, turbine location and prey appear to play roles**
- **Not all turbines appear to contribute to fatalities**

Data Points Only Analyzed Under 300m Mask



Altamont Pass
Flight Observations

The terrain relief map shows avian flight observations within 300 m of a set of target turbines.

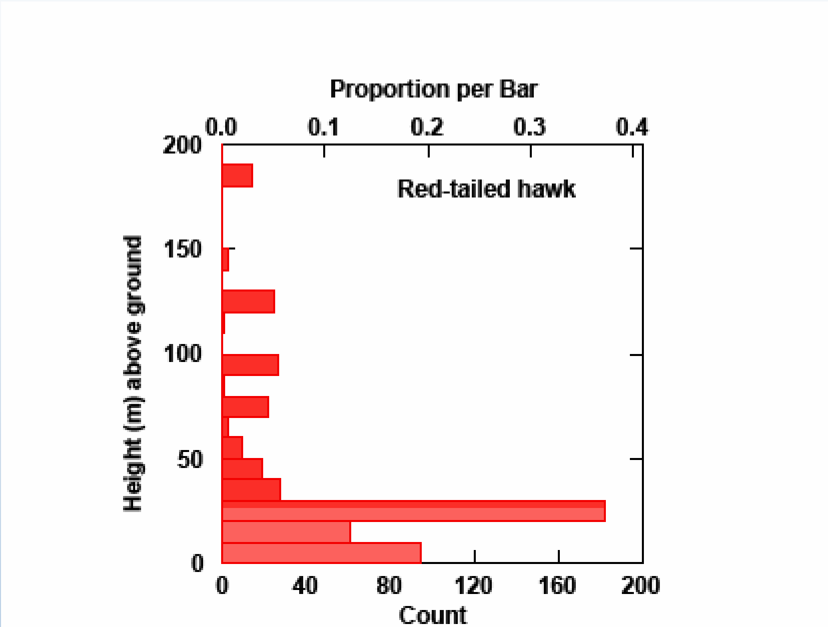
- Note the non-uniform avian use distribution around the turbines
- Period of observations 15 October 2002 through 14 May 2003

Source: K. Smallwood and L. Neher, CEC-500-2005-005, December 2004

Could preconstruction studies develop a bird probability density map to illuminate high usage flight zones through a proposed windfarm?

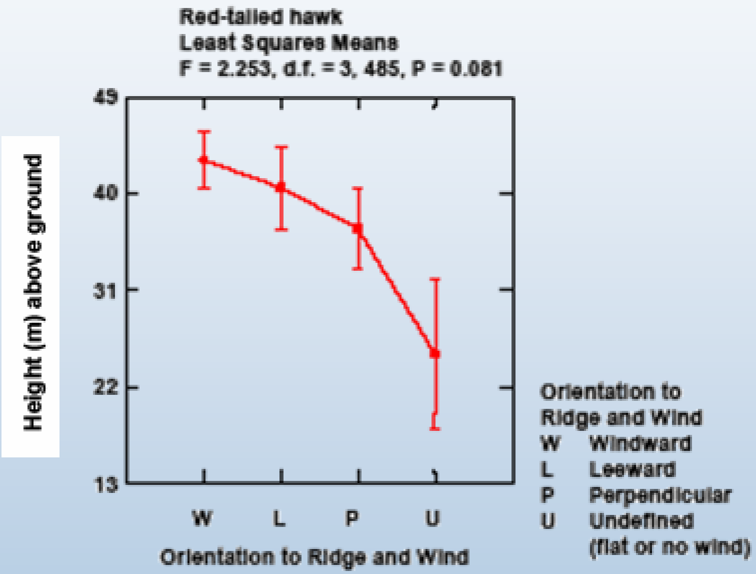
Red Tailed Hawk Flight Observations Histogram for Altamont Pass

Height Histogram



Distribution of flight heights above ground level amount red-tailed hawks observed during behavioral observations sessions during 2003 and 2004 in the APWRA.

Height versus Orientation

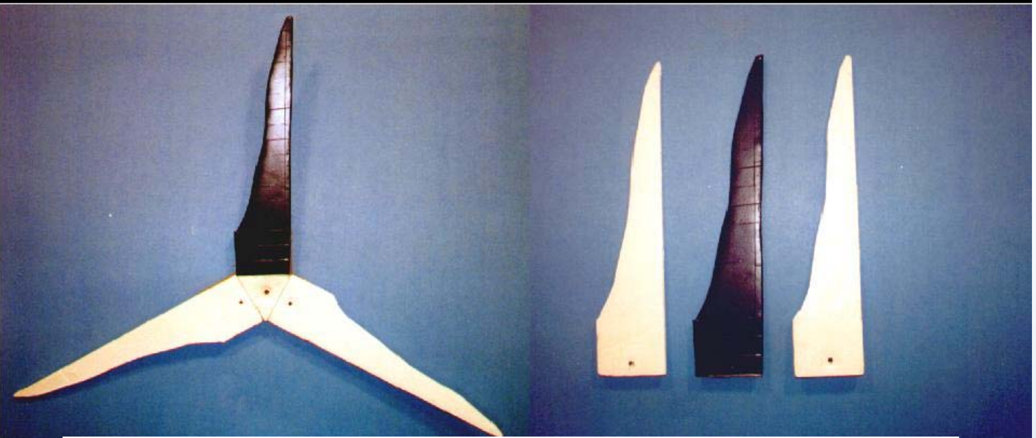


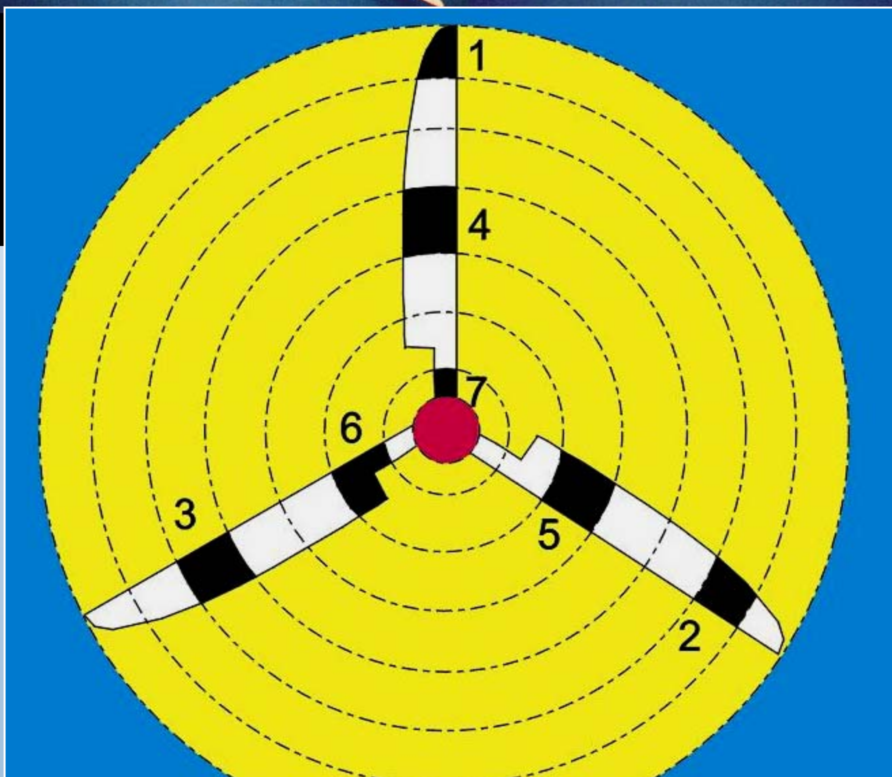
Mean flight heights of red-tailed hawk over aspect of ridge relative to oncoming winds.

Source: K. Smallwood and L. Neher, CEC-500-2005-005, December 2004

NREL National Renewable Energy Laboratory

Avian Risk Reduction: Visual Enhancement to Increase Avoidance



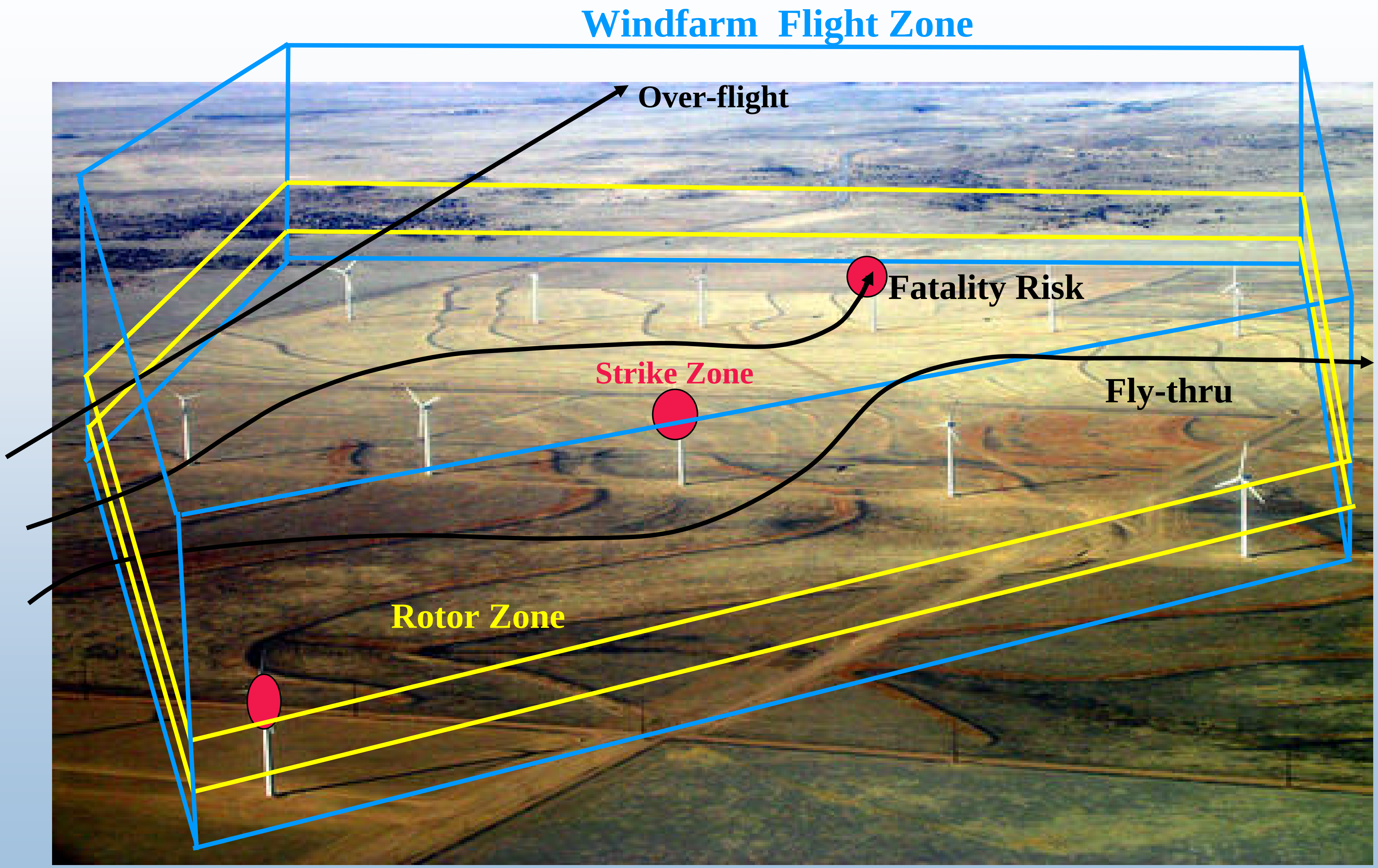


Visual Patterns

American Kestrel

Source: *The Role of Visual Deterrents in Reducing Avian Collisions;* William Hodos, University of Maryland

Visualization of Avian Interaction Zones



Candidate Avian Risk Metrics

Hypothesis: "Mortality risk increases with flight time in the rotor zone (yellow zone), if the turbine is operating"

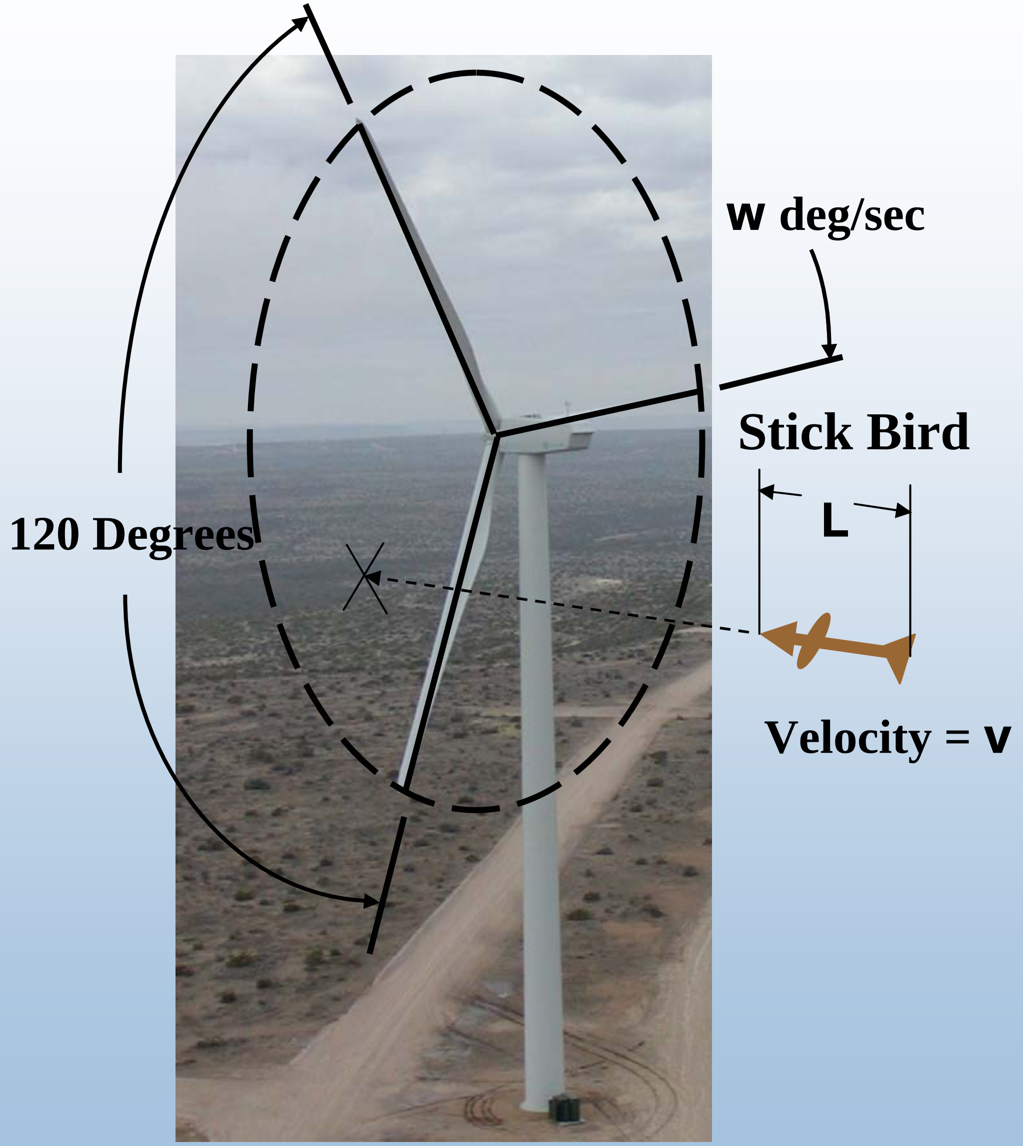
- **A Candidate Post-construction Fatality Metric:**

  Species Risk = Fatalities/(Swept Area x Turbine Operation Hours)

- **A Candidate Preconstruction Relative Risk Metric:**

  Species Relative Risk = (Flight Hours in Rotor Zone with Wind in Operating Range)/(Plant Swept Area x Hours with Wind in Operating Range)

A Simple Stick Collision Model



Stick Turbine

Bird passage time through the rotor:

$t_p = L/V =$ **Length speed ratio** (sec)

Blocked Sector of Turbine Rotor:

$B = t_p\, w$ (deg)

Probability of collision:

$P_c =$ Blocked Area / Disk Area

$P_c = 3B/(360\text{deg})$

$P_c = 3(L/V)\{w(\text{deg/sec})/360\text{deg}\}$

To account for avoidance:

$P_c = 3\,A\,(L/V)\{w(\text{deg/sec})/360\text{deg}\}$

$$\text{where } A = \begin{Bmatrix} <1 \text{ for avoidance} \\ 1 \text{ for no behavior} \\ >1 \text{ for attraction} \end{Bmatrix}$$

Avian Strike Probability Versus Turbine Size

Altamont Scale

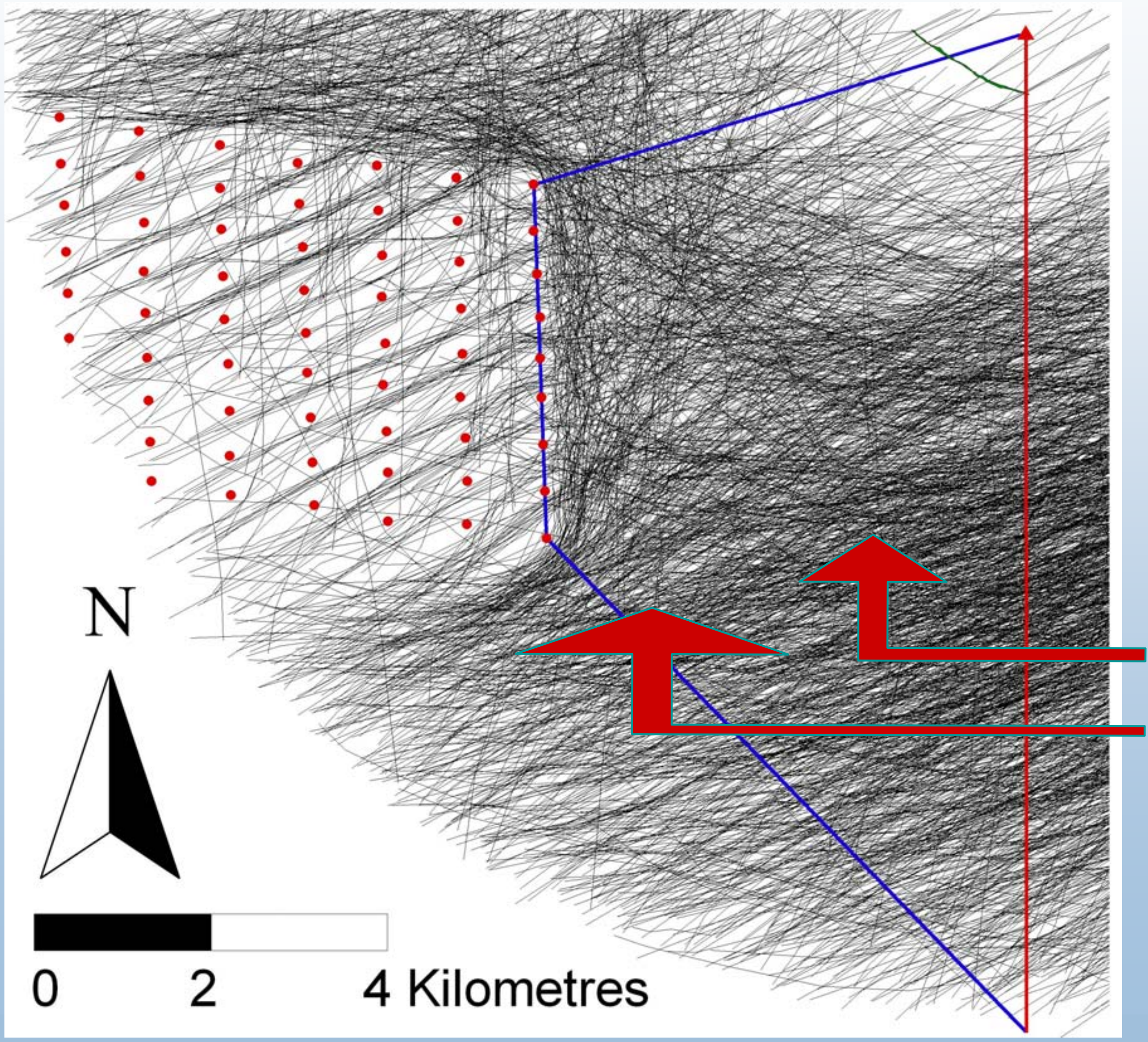
15 Meter Diameter and 100 kW

Next Generation Scale

93 Meter Diameter and 2.5MW

Avoidance Behavior is Significant

Radar Tracks of Migrating Birds through Nysted Offshore Windfarm for Operation in 2003

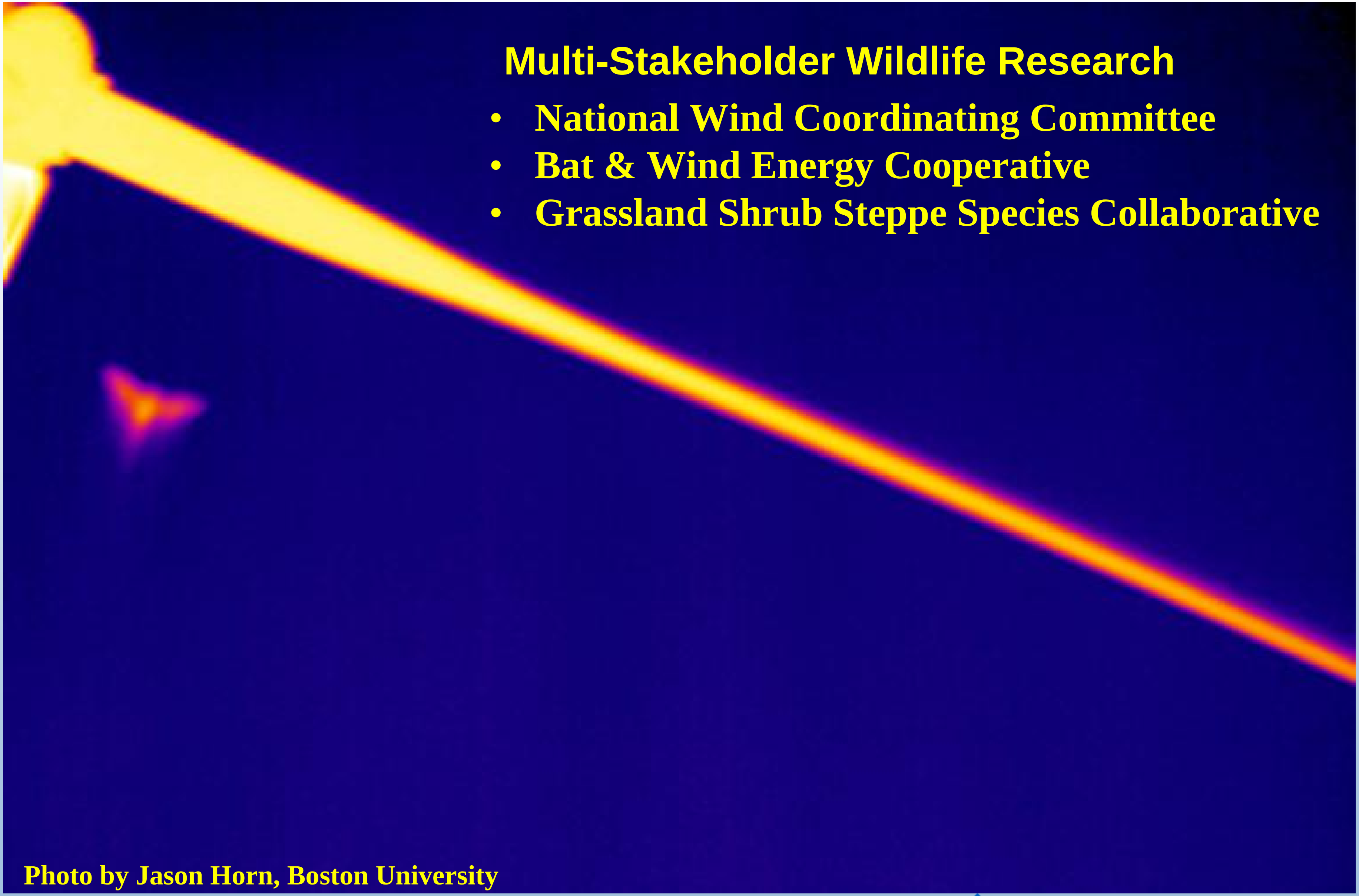


Response distance:

day = c. 3000m

night = c. 1000m

Infrared Image of a Bat Flying Through a Wind Turbine Rotor

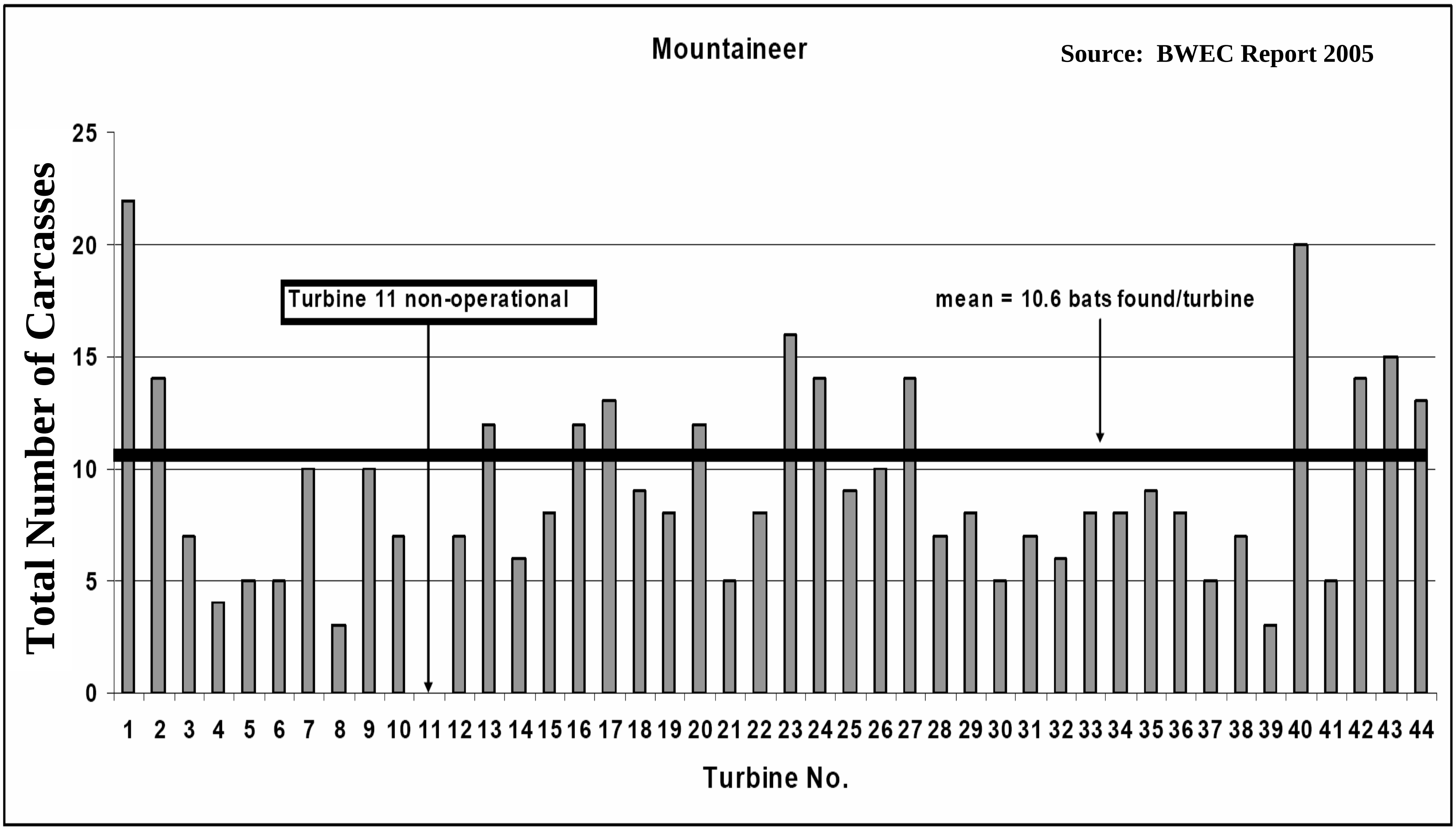


Multi-Stakeholder Wildlife Research

- National Wind Coordinating Committee
- Bat & Wind Energy Cooperative
- Grassland Shrub Steppe Species Collaborative

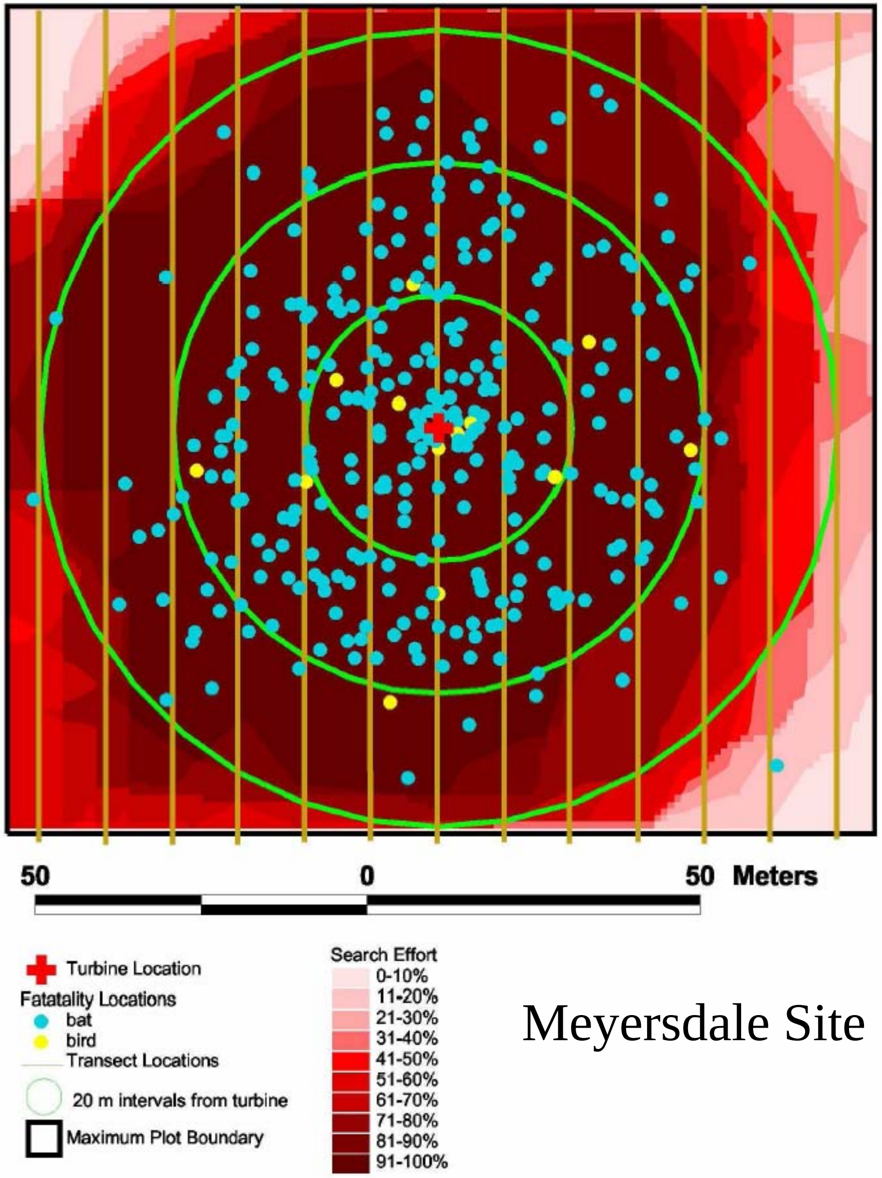
Photo by Jason Horn, Boston University

BWEC Study Results



Number of bat fatalities found at each turbine during the study period.

BWEC Study Results



Meyersdale Site

Meyersdale Wind farm:

- NEG – Micon 1.5 MW Turbine
- 72 meter rotor Diameter
- 17 revs/min = 102 deg/sec
- Constant rotor rpm
- Green dots are bat carcasses
- Yellow dots are birds
- Bird and bat fatalities for all 20 turbines are overlaid

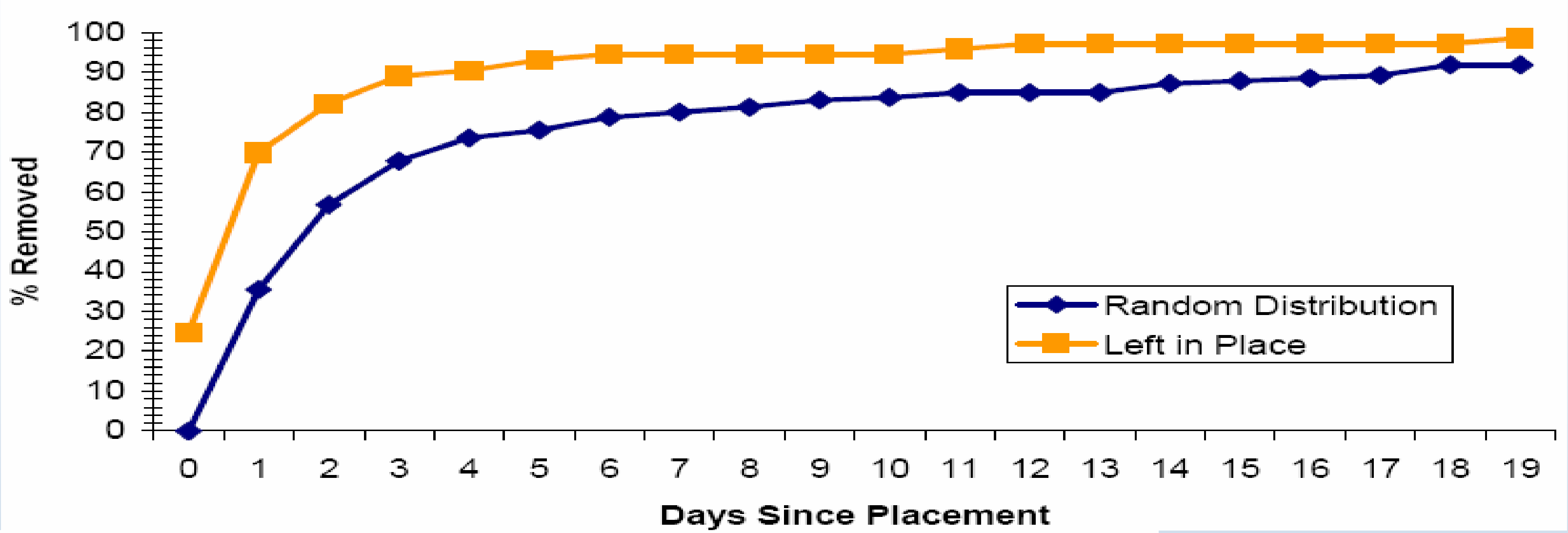
Observations:

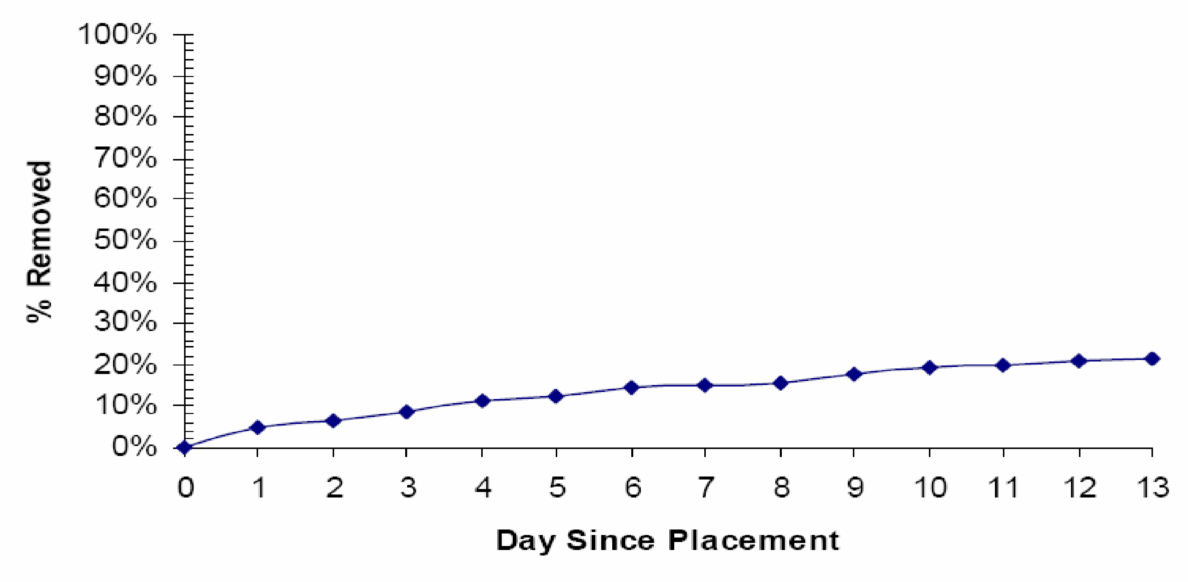
- Bird and bat fatalities appear to be fairly uniformly distributed out to 40m
- Beyond a radius of about 40m fatalities drop off rapidly indicating carcasses are not thrown far outside of the blades span
- The higher velocity tip regions of the blade do not seem to be more dangerous than the root near the tower
- Bats are much more vulnerable than birds

Source: BWEC Report 2005

BWEC Savaging Study Results

Removal by scavengers

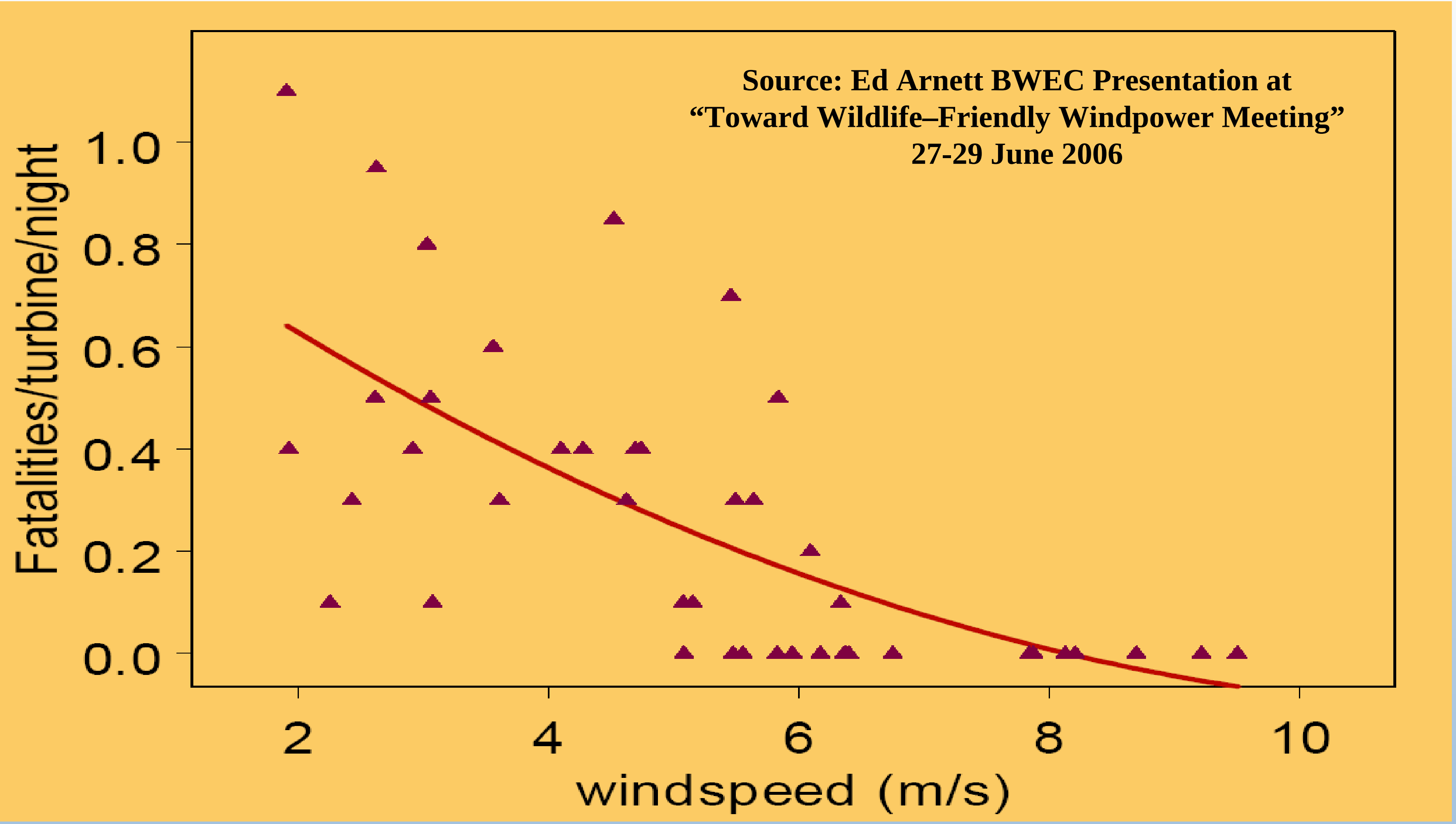




Source: BWEC Report 2005

BWEC Study Results

Fatalities decrease with increasing wind speed



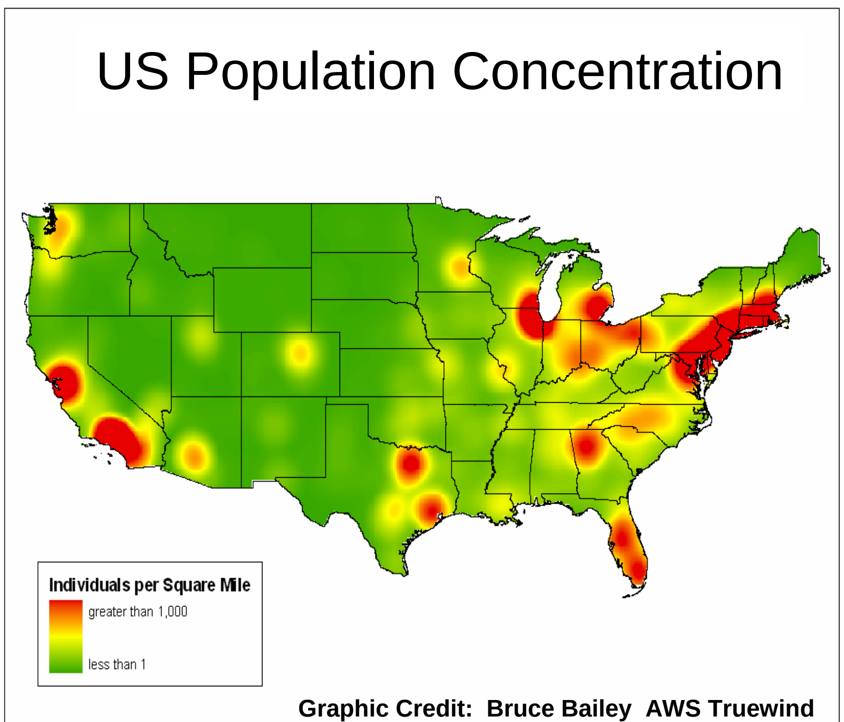
Offshore Wind – U.S. Rationale

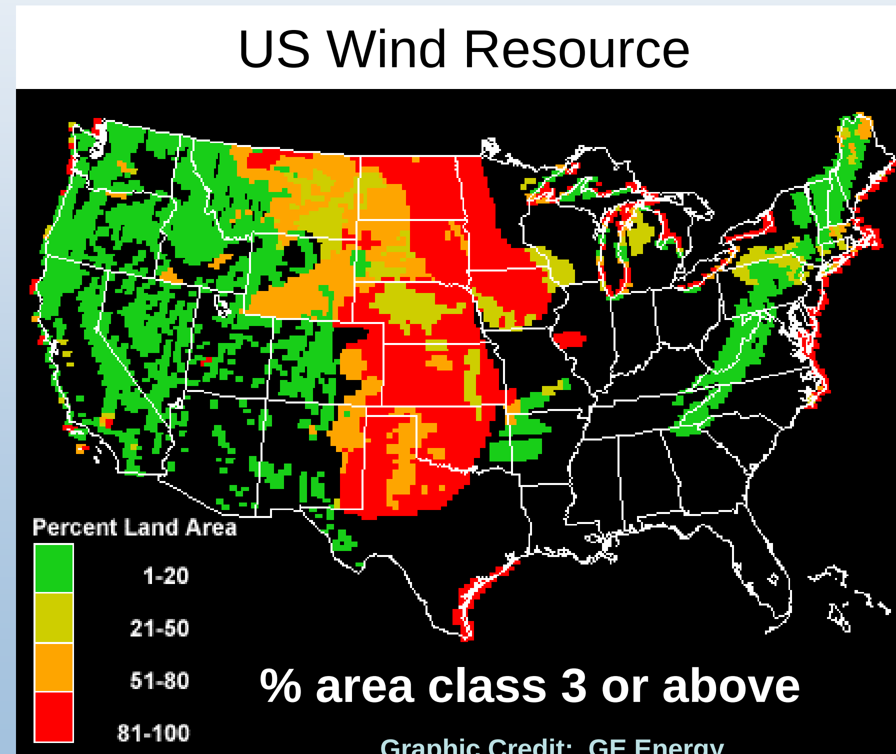
Why Go Offshore?

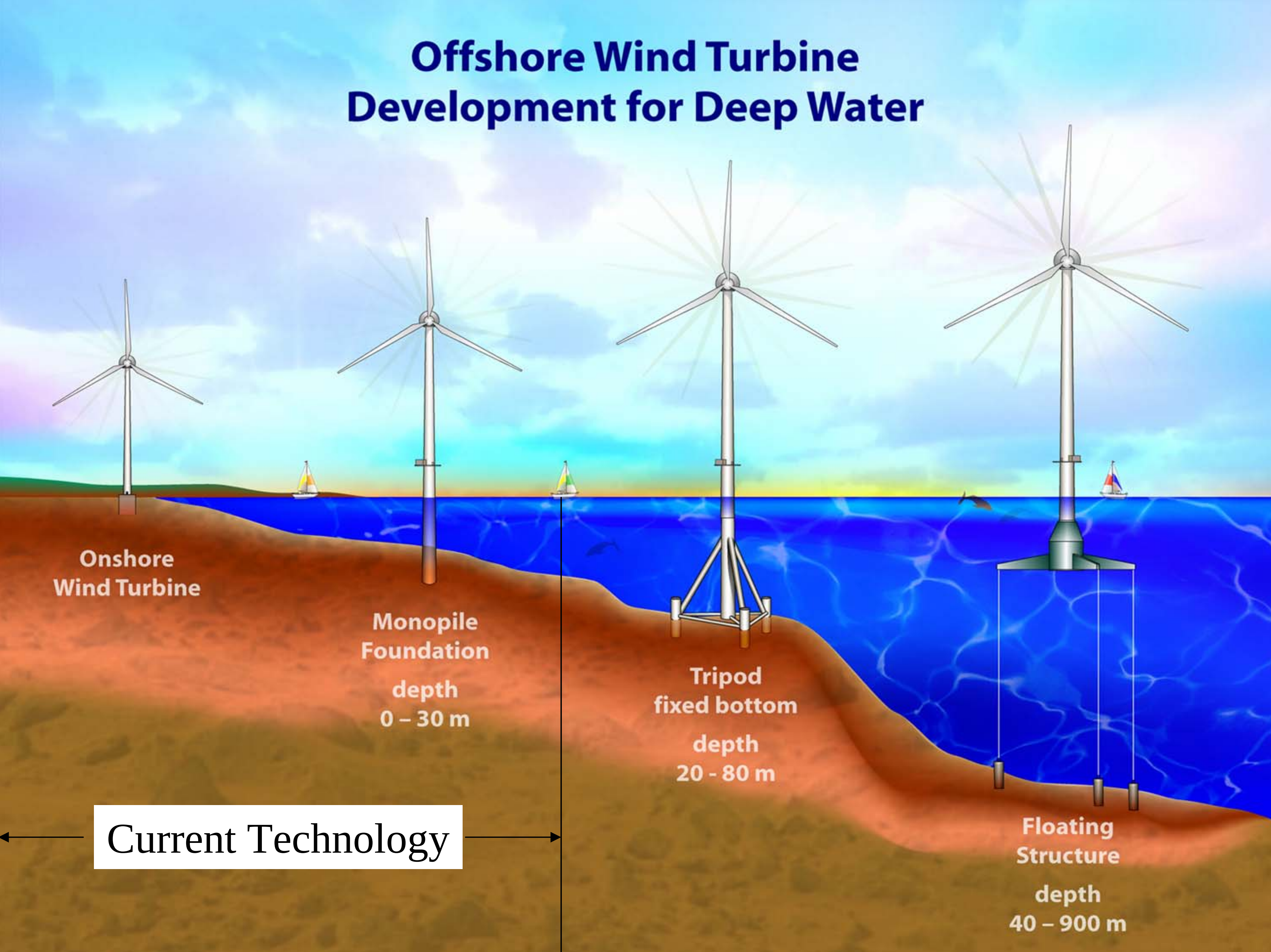
Windy onshore sites are not close to coastal load centers

The electric utility grid cannot be easily set up for interstate electric transmission

Load centers are close to the offshore wind sites





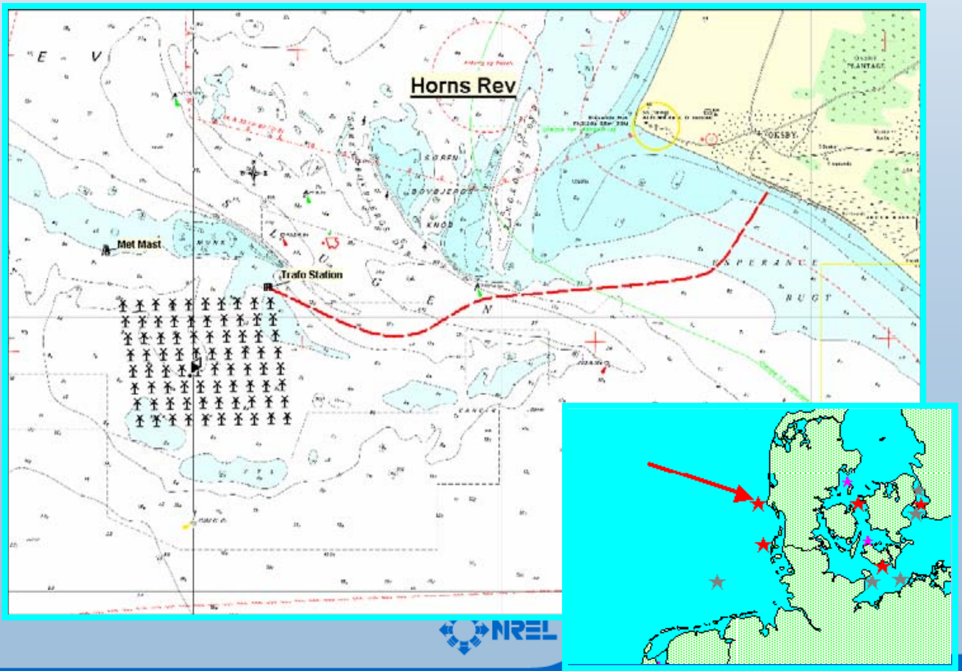

Offshore Wind Turbine
Development for Deep Water
Onshore
Wind Turbine
Monopile
Foundation
depth
0 – 30 m
Tripod
fixed bottom
depth
20 - 80 m
Floating
Structure
depth
40 – 900 m
Current Technology

Arklow Banks Windfarm
The Irish Sea

Photo: R. Thresher

Horns Rev Wind Farm Installation

Country: Denmark
Location: West Coast
Total Capacity: 160 MW
Number of Turbines: 80
Distance to Shore: 14-20 km
Depth: 6-12 m
Capital Costs: 270 million Euro
Manufacturer: Vestas
Total Capacity: 2 MW
Turbine-type: V80 - 80m diameter
Hub-height: 70-m
Mean Windspeed: 9.7 m/s
Annual Energy output: 600 GWh

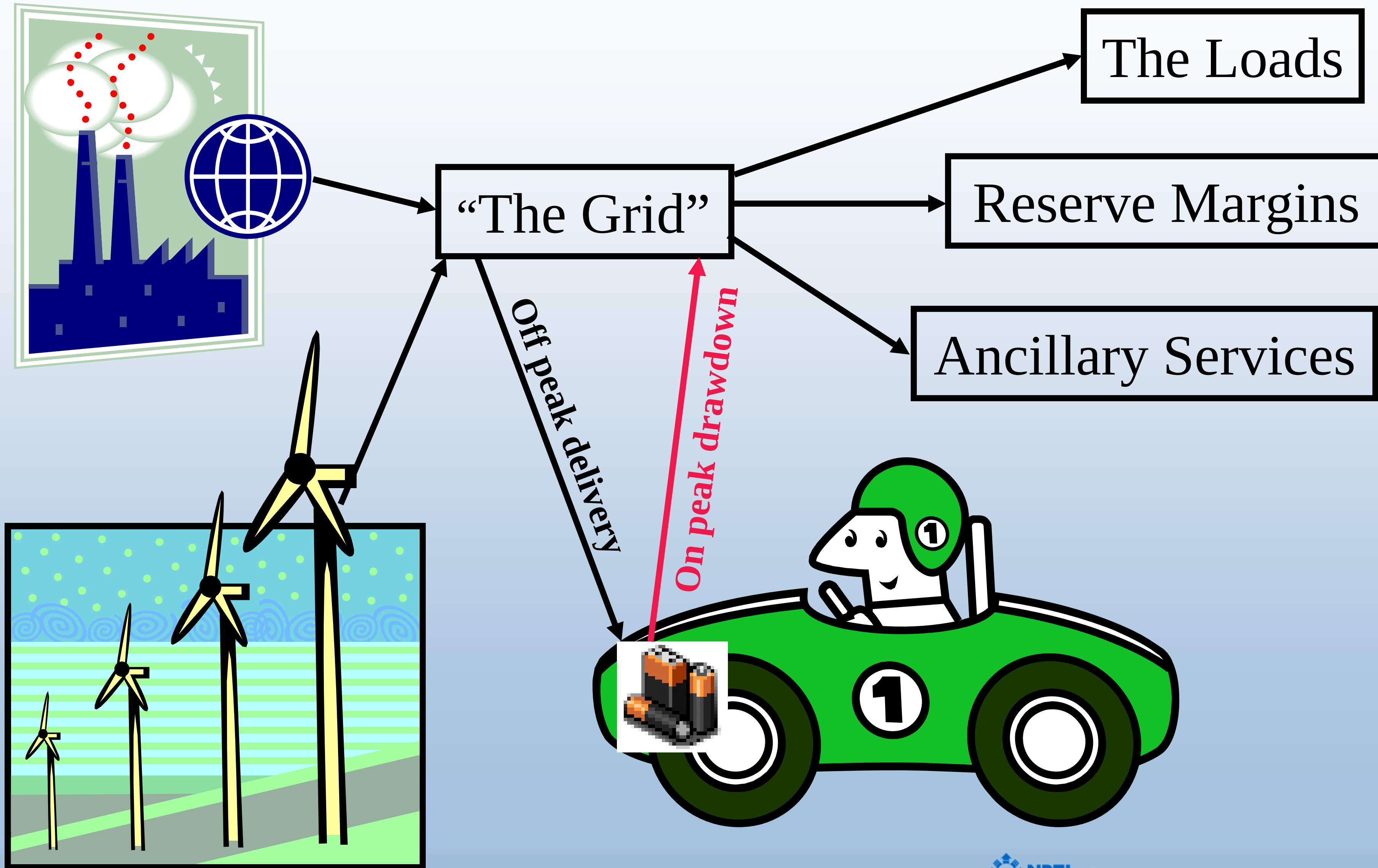


Offshore Wind
European Environmental References

- European Union, COD, Principal Findings 2003-2005, prepared by SenterNovem, Netherlands, www.offshorewindenergy.org
- Offshore Wind: Implementing a New Powerhouse for Europe, Greenpeace International, March 2005 http://www.greenpeace.org/international/press/reports/offshore-wind-implementing-a
- Danish (Horns Rev and Nysted) Ecological Studies http://www.hornsrev.dk/Engelk/default_ie.htm and http://uk.nystedhavmoellepark.dk/frames.asp?Page_ID=44&Page_Ref=44&Templates_ID=1
- U.K.'s Strategic Environmental Assessment http://www.og.dti.gov.uk/offshore-wind-sea/process/envreport.htm

Plug Hybrid Electric Vehicles

(A Future Off-Peak Electricity Market with Storage)



A Future Vision for Wind Energy Markets

Today 2006

Bulk Power Generator
5-8¢ at 13mph*
With No PTC

- Land Based
- Bulk Electricity
- Wind Farms

Less than 1% of Electricity Market

Tomorrow

Land Based Electricity Path → **Land Based LWST Large-Scale 2–5 MW** → **Transmission Barriers** →

LWST Turbines:
- 3.6¢/kWh at 13mph*
- Electricity Market

2012

Offshore Electricity Path → **Offshore Turbines 5 MW and Larger** → **Cost & Regulatory Barriers** →

Offshore LWST Turbine:
- 5 cents/kWh
- Shallow/***Deep*** *water*
- Electricity Market
- Higher wind Sites

2014 and Beyond

Advanced Applications Path →
- **Hydrogen**
- **Clean Water**
- **Plug Hybrids**

→ **Cost & Infrastructure Barriers** →

Custom Turbines for Multi-markets:
- Electricity
- H2 production
- Desalinate water
- Transport & Storage

2020 and Beyond

* Note: The site wind speed is measured at 10m and assumes a 1/7 power law wind shear giving a hub height wind speed of 18mph, while the siting, land and related project costs are assumed to be average for the US.

GE Wind 1.5 MW – Windfarm Projects

Concluding Remark

World-wide electrical energy consumption is projected to grow by about 75% over the next 20 years. All energy technologies have some environmental impacts. Wind Technology is developing rapidly, and a modest investment in environmental R&D now could make the impacts negligible. This would give us a carbon free electricity generating choice that could meet at least 20% of the world's energy needs.

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